W 70-08186 16010 10/69

PB192760

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va. 22151

PLANKTON COMMUNITY AND HYDRAULIC CHARACTERIZATION PRELIMINARY TO LAKE FLUSHING

E. B. Welch · R. J. Buchanan
R. H. Nece · R. H. Bogan

University of Washington
College of Engineering
Department of Civil Engineering

October 1969

188

PLANKTON COMMUNITY AND HYDRAULIC CHARACTERIZATION PRELIMINARY TO LAKE FLUSHING

by

Eugene B. Welch, Assistant Professor of Applied Biology
Ronald J. Buchanan, Senior Research Associate
Ronald E. Nece, Professor of Civil Engineering
Richard H. Bogan, Professor of Civil Engineering

College of Engineering
Department of Civil Engineering
Water and Air Resources Division
University of Washington
Seattle, Washington 98105

October, 1969

TABLE OF CONTENTS

Page

INTRODUCTION 1

DESCRIPTION OF THE STUDY AREA 5

METHODS AND MATERIALS 7

- Integrated Water Sampling - Biological and Chemical 7
    - Chemical Analyses 9
    - Plankton Sample Analysis 9
    - Plankton Data Analysis 9
    - Plankton Experiments 12
    - Monitor Data Evaluation 12
- Hydraulic 12
    - Topography 12
    - Hydraulic 13

RESULTS 14

- Biological 14
    - Plankton Community Analyses 14
    - Cluster Analysis 18
    - Notes on the Characteristics of Sample Groups 18
    - Plankton Crops and Associated Factors - Seasonal Variation 55
    - Plankton Experiments 61
    - Plankton Crops and Productivity - Diurnal Variation 66
- Hydraulic 72
    - Objectives and Emphasis of Data 72
    - Inflow and Crab Creek Data 74
    - Time of Travel Studies, Upper Basin 79
    - Flushing Times 90
    - Lower Basin (Main Parker Horn) 94
- Modeling Algal Productivity and Distribution 96
    - Proposed Model 96
    - Model Equations 98
    - Evaluation of Model Variables 99

DISCUSSION 101

- Biological 101
- Hydraulic-Model Feasibility 104

SUMMARY AND CONCLUSIONS 107

LITERATURE CITED 109

APPENDIX A - FORTRAN IV PROGRAM LISTINGS 110

Page

APPENDIX B - MANUSCRIPT FOR PUBLICATION, DERIVED IN PART, FROM THE MOSES LAKE STUDY 139

APPENDIX C - TAXONOMIC NOTES ON ALGAE AND PROTOZOA FROM MOSES LAKE 167

LIST OF FIGURES

Page

Figure 1. Map of Moses Lake. 2

Figure 2. Plan of Moses Lake, showing sampling transects. 8

Figure 3. Trellis diagram of half the Moses Lake samples collected between July 30, 1968 and May 22, 1969 (every odd-numbered sample when ranked in order of collection) after cluster analysis. The distribution of these sample groups throughout the lake and with time are shown on accompanying maps of the lake. 23

Figure 4. Sample group similarities. 41

Figure 5. Species group similarities. 45

Figure 6. Correspondence between species groups and sample groups. 46

Figure 7. Comparison of chlorophyll a content (at .4 m) and light intensity at 1 meter depth throughout Moses Lake during 1968 and 1969. Dashed line is chlorophyll a and solid line is estimated light intensity at 1 meter. Right ordinate in μg/l chlorophyll a and left ordinate in langleys per day light intensity at 1 meter. 56

Figure 8. Comparison of mean chlorophyll a content of all stations in Parker Horn (Stations A, B, C) and Pelican Horn (Stations H, I, J, K) during part of 1968 and 1969. 57

Figure 9. Relation between phytoplankton concentration in cell counts and monthly average lake-water outflow during 1963. Counts were made in samples collected from 1 meter depths at locations similar to stations in 1968-69. These data from Sylvester and Oglesby, 1963. 59

Figure 10. Comparison of total- and ortho-phosphate phosphorus at .4 m throughout Moses Lake during 1968 and 1969. Dashed line is ortho-phosphate and solid line is total phosphate. Ordinate in mg/l phosphorus. 60

Figure 11. Dissolved Oxygen-Depth Relationships at Station G - representing periods of mixing and stratification during June, 1969. 63

Figure 12. Temperature-Depth Relationships at Station G representing periods of mixing and stratification during June, 1969. 64

Figure 13. Diurnal variation in Chlorophyll a content at indicated depths at Station C (one point) on August 19, 1969. 67

Figure 14. Diurnal variation in the vertical distribution of chlorophyll a content at Station C (one point) on August 19, 1969. 68

LIST OF FIGURES (continued)

Page

Figure 15. Variation in the vertical distribution of chlorophyll a content at station C (one point) on August 14, 1969. 70

Figure 16. Gross productivity and respiration measured at 2 hour intervals and 5 depths at station C (one point) on August 19, 1969. 71

Figure 17. Daily solar radiation (tope graph) and comparison of rate of O_2 change in bottle experiments with in situ measurements at Station C (bottom graph) on July 24, 1969. 73

Figure 18. Time-Concentration Curves of Dye at State Highway Bridge - 1968 Preliminary Studies. 75

Figure 19. Crab Creek, Wasteway, and Total Inflow, 1968. 76

Figure 20. Crab Creek, Wasteway, and Total Inflow, 1969. 77

Figure 21. Upper Basin Inflow Correlation. 78

Figure 22. State Highway Bridge, Railroad Bridge, and Alder Street Bridge Topographic Cross-Sections. 80

Figure 23. Moses Lake Water Surface Elevations at Interstate 90 Highway Bridge. 81

Figure 24. Drogue paths. 84

Figure 25. Data collection points 24, 25 May, 1969. 85

Figure 26. Data collection points 28, 29 June, 1969. 86

Figure 27. Integrated Velocity Time-of-Travel from Railroad Bridge. 88

Figure 28. Drogue Study Time-of-Travel from Railroad Bridge. 89

Figure 29. Dye Study Time-of-Travel from Railroad Bridge. 91

Figure 30. Time-Concentration Curves for Dye Study of 24 May, 1969. 92

Figure 31. Comparison of 28, 29 June, 1969 Time-of-Travel Data with Jet-Diffusion Model. 93

Figure 32. Multicompartment Model of the Parker-Lewis Horn Portion of Moses Lake. 97

LIST OF TABLES

Page

TABLE I. Segment Characteristics of Moses Lake. 6

TABLE II. Complete list of organisms found in Moses Lake plankton samples. 15

TABLE III. Listing of samples in the sample groups identified among the 173 samples collected from Moses Lake, Washington, from July 30, 1968 to May 22, 1969. 19

TABLE IV. Listing of the species in eight species groups identified from half the Moses Lake samples collected between July 30, 1968, and May 22, 1969, (every odd-numbered sample when ranked in order of collection). 42

TABLE V. Sample Group Mean Values (Physico-Chemical Data). 47

TABLE VI. Sample Group Coefficients of Variation ($\frac{\sigma}{x}$ x 100) Parentheses enclose the no. of samples upon which the statistics were determined. 48

TABLE VII. Number of Representatives of Toxonomic Classes in Each Sample Group. Representatives in Sample Groups (#Detected/ #>5 per ml). 49

TABLE VIII. Summary of the temporo-spatial distribution of sample group members (biotic community types) in Moses Lake between July 30, 1968 and May 22, 1969. 50

TABLE IX. Comparison of the principal parts of the phosphorus budget for Moses Lake determined in 1963-64 and again in 1968-69. Values in pounds/day as phosphate-phosphorus. 62

TABLE X. Relative chlorophyll a gross photosynthesis, total and orthophosphate as % of control. Experiment conducted in 2.8 m deep, 0.78 m diameter plastic bags from July 10 to 20, 1969. 65

TABLE XI. Summary of Field Studies. 87

INTRODUCTION

Cultural eutrophication, or the accellerated aging of standing water bodies, is presently one of the most serious problems of water quality degredation. The increased pressure of urbanization and desire to live near recreation sites leads to full "development" of lake basins which will certainly accentuate eutrophication problems in the years ahead. Quantitative predictions on the impact of degrees of development are urgently needed to adequately control this process.

Although the macronutrients nitrogen and/or phosphorus are generally considered the prime cause(s) for this accellerated aging, the effect from a given input of nutrient can vary greatly depending on the morphometry, hydraulic detention time and inherent water chemistry to name but a few. Because of the interrelation of nutrient effects with other important factors that contribute to the control of plankton productivity, any hope for control criteria will likely come from large scale experiments in which certain important environmental factors are varied on a large scale. Effects from given perterbations are apt to be most reliable over at least a year so that biological communities reach some equilibrium with the degree of environmental variation. Examples of such large-scale "experiments" include diversions of sewage around the Madison Lakes in Wisconsin and from Lake Washington in the Seattle area. Recent diversion of the major waste nutrient income from Lake Sammamish east of Seattle has resulted in interest in the resulting recovery rate of this important recreation lake. Another environmental alteration to control eutrophication, where sources of nutrients are diverse, is the addition of fairly large quantities of low-nutrient flushing water such as was done in Green Lake in Seattle. The highly successful nature of this endeavor was reported on by Oglesby (1, 2).

Two effects of the flushing water on the nusiance algal populations would result from dilution of nutrients to presumably limiting levels and washout of phytoplankton cells. Another possible effect would be to reduce the "age" of the water and consequently the "conditioning" of the medium with inhibitory or stimulatory extretory metabolites from the algal populations. The use of flushing water would likely be facilitated if the relative magnitude of these separate effects could be determined.

As a brief background, the original purpose of this research project was to evaluate the effect of adding varying amounts of low-nutrient flushing water to one area of Moses Lake, a 6,500 acre highly eutrophic lake in Eastern Washington. As shown in Figure 1 Moses Lake has an irregular shape with the City of Moses Lake being located around the two principal horns at the southeastern end. The principal tributary, Rocky Ford Creek, enters at the northern end and a second, Crab Creek, through upper Parker Horn. Also shown is the Rocky Coulee Wasteway, a Bureau of Reclamation structure which constitutes a physical connection of the lower lake to the East Low Canal, a major distributor of irrigation water from the Grand Coulee project. A nutrient budget for Moses Lake indicated that levels of nitrogen and phosphorus in Rocky Ford Creek and in surface and subsurface seepage from irrigated land adjacent to the lake were of such an order of magnitude that preclusion was clearly infeasible. However, the existence

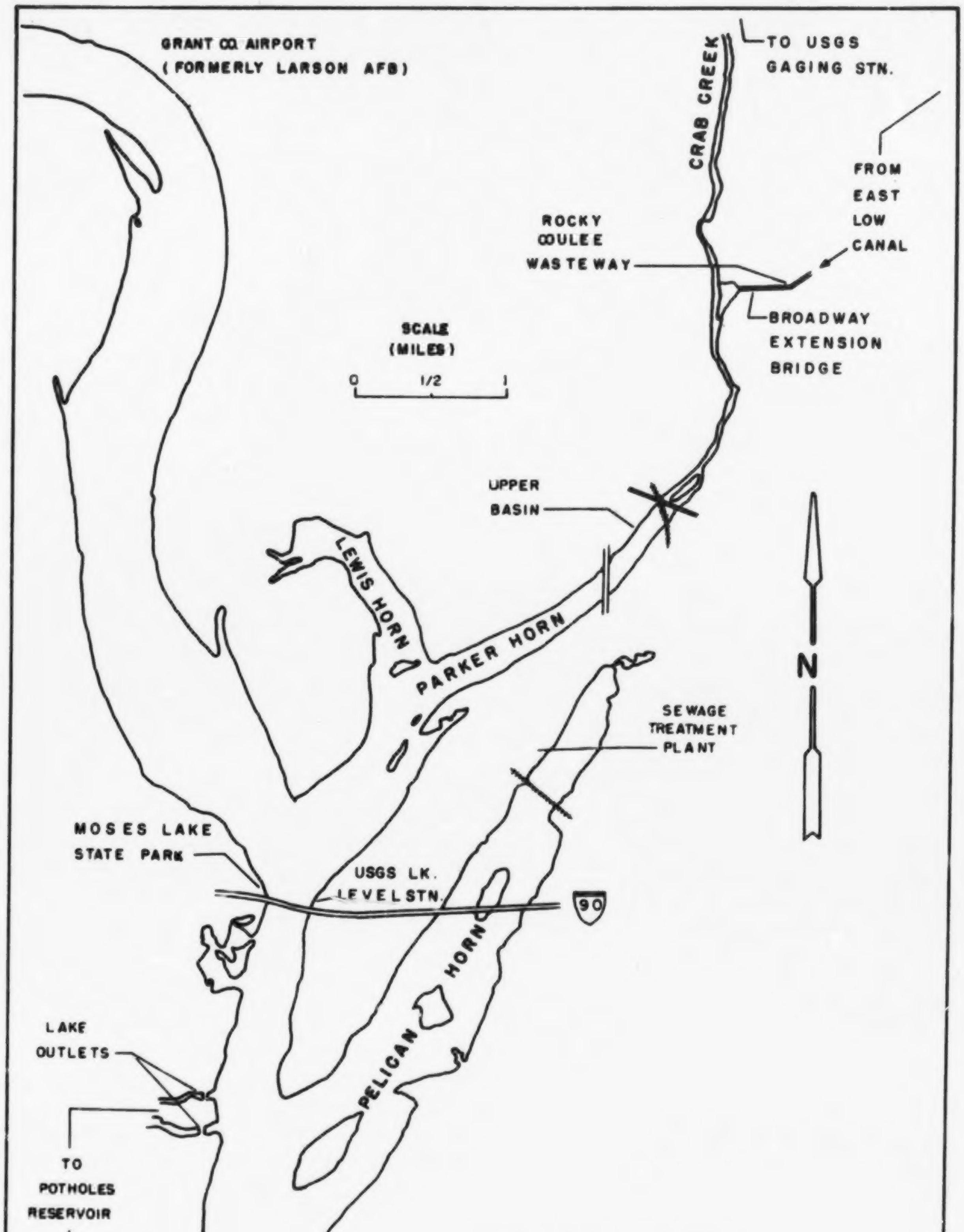

GRANT CO. AIRPORT
(FORMERLY LARSON AFB)
CRAB CREEK
TO USGS GAGING STN.
FROM EAST LOW CANAL
ROCKY COULEE WASTEWAY
BROADWAY EXTENSION BRIDGE
SCALE (MILES)
0
1/2
1
UPPER BASIN
LEWIS HORN
PARKER HORN
N
SEWAGE TREATMENT PLANT
MOSES LAKE STATE PARK
USGS LK. LEVEL STN.
90
PELICAN HORN
LAKE OUTLETS
TO POTHOLES RESERVOIR
MOSES LAKE

Figure 1. Map of Moses Lake

of a hydraulic structure connecting Moses Lake with a source of water very low in nutrients and essentially devoid of suspended material, suggested the possibility of instituting a flushing program similar to that initiated in Green Lake.

Contact with the U. S. Bureau of Reclamation revelaed that irrigation water is not regularly released into Moses Lake through the Rocky Coulee Wasteway. Occasionally water is released through Rocky Coulee Wasteway at the start and end of the irrigation season to flush out the system. During spring and early autumn large quantities of irrigation water bypass the Lake and are fed into the Potholes Reservoir to the south, and stored against the demands of the next agricultural season. Moses Lake is directly connected to this large holding reservoir and, hence, the water could easily be diverted on a circuit through the Lake. There would be no necessity for building new structures to implement such a program and the needs of the Bureau of Reclamation would still be met. It was calculated that in the event a flushing program could be begun, the nutrient content of the 8,000 acre feet of water in Parker Horn could conceivably be lowered to levels where nuisance blooms would not occur. The increased washout of phytoplankton and further dilution in the rest of the lower lake were also postulated as leading to significant water quality improvements in this larger area.

Such a program was recommended by Sylvester and Oglesby (3) based on an earlier study in 1963 but action by local authorities to implement this suggestion was slow in coming. In 1967 when the submission of this proposal was considered, the Moses Lake Irrigation and Rehabilitation District was contacted. They reported that earlier in the year a temporary diversion of East Low Canal water through the Lake was carried out at the request of the Bureau of Reclamation and that improvements in water quality were dramatic. With this encouragement, some 500 acre feet of water was purchased and introduced through the Wasteway in the summer of 1967 as a pilot experiment. Unfortunately, a storm with high winds arrived at Moses Lake on the same day that flushing water was added. However, both direct sampling and analysis of water quality and aerial photography indicated that substantial, if temporary, improvements could be seen [Nunnallee (4)].

The experimental approach in the present project was originally designed to study the effects of low nutrient Columbia River water on algal growth when introduced at different rates (up to 25,000 acre feet) into Parker Horn of Moses Lake. By relating changes in algal growth with various hydraulic flow patterns and degrees of nutrient dilution from a system analysis approach it was hoped that the functional performance and effectiveness of flushing as a means of eutrophication control would be tested and evaluated. As a result the engineering concepts, design procedures, and design criteria necessary for general application of the method could be defined. An uncooperative atmosphere developed in the irrigation districts after the study was initiated which led to disapproval of Columbia River water for purposes of experimental flushing. Thus, the original objective of testing the effectiveness of different models through scheduled releases of water during the period of maximum algal growth was not feasible.

With the use of experimental flushing water to evaluate its effect on lake algae denied, effort was placed into describing as much of the plankton community temporal and spatial distribution and hydraulic characteristics as was possible in the limited time remaining in the project year. An extension of time was granted which made possible development of the background characteristics reported here. Possible relationships of plankton biomass and community types with environmental factors were searched for but was largely hampered by insufficient data at the time of this writing. We feel that to adequately evaluate the effect of flushing, more thorough background data on the lake than previously existed would be necessary. A complete account of the plankton species composition and mass throughout the lake and during a full year was not available. Surely such information would be necessary in order to define the extent and duration of the flushing effect in different segments of the lake. With modest support from the Washington Water Research Center, development of these needed background data is continuing along with *in situ* experiments designed to test the effects of low-nutrient dilution water and water "aging" on nuisance algal growth. Eventually the inter-district disputes should clear and apprehention on the part of irrigation representatives subside. At that time, water for experimental purposes should become available and needed research in this area would again be possible.

DESCRIPTION OF THE STUDY AREA

Moses Lake is relatively large (about 6,500 acres), shallow (mean depth 19.3 feet) and considerably dissected in form. The lake is natural and is located approximately 100 miles southwest of Spokane, in East Central Washington. It was originally formed by wind-borne sand dunes that dammed a valley. Other pertinent morphometric data that describe the lake are shown in Table I.

Climate in the area is very dry, with about 7 inches of rainfall per year and mostly warm and sunny days during the summer. Because the area surrounding the lake has relatively little relief and tree cover, the lake is greatly exposed to the wind.

As mentioned earlier, surface water inflow enters through Rocky Ford Creek, Crab Creek and occasionally through Rocky Coulee Wasteway in the form of unscheduled irrigation water releases to flush out the canals at the beginning and end of the irrigation season. The other main source of inflow enters as ground water. The lake elevation of 1,048 feet is maintained by a dam at the outlet, through which flow is recorded.

The population around the lake, mostly concentrated in the city of Moses Lake between Parker and Pelican Horns, exceeds 20,000. Domestic waste from the city is given secondary treatment by trickling filter and released into mid Pelican Horn. The growth of the city has resulted primarily from increased agricultural activity facilitated by the Columbia Basin Irrigation Project of the U.S. Bureau of Reclamation. Military establishments have also contributed to the growth.

The lake is used extensively for fishing, boating and water skiing. If nuisance algal growth could be controlled during the warm summer months, recreational potential of the lake would be enhanced and use would no doubt greatly increase.

SEGMENT	VOLUME (acre-feet)	AREA (acres)	MEAN DEPTH (feet)
Total Lake (1)	126,000	6800	18.5
Lake Above (1) Parker Horn	81,000	3790	21.4
Total (2) "Flushable"	45,000	----	-----
Parker Horn (1)	9,520	758	12.6
Lewis Horn (3)	2,180	217	10.0
Pelican Horn (3)	21,000	1340	15.7
Lower Main (3) Lake	12,300	----	----
Upper Basin of (4) Parker Horn	179.2	44.7	4.0

(1) Sylvester and Oglesby, water surface elevation 1046.0 ft.

(2) Assuming no interchange with main lake.

(3) Estimated.

(4) Water surface elevation 1046.5 ft.

TABLE I. Segment Characteristics of Moses Lake.

METHODS AND MATERIALS

Integrated Water Sampling - Biological and Chemical

Since Moses Lake is obviously sectionalized into a series of morphometrically distinct segments, the sampling program was designed to illucidate these differences from a biological and chemical standpoint. Two principal surface water inflows, Rocky Ford Creek and Crab Creek, and the lake outflow were sampled for nutrient content coincident with lake sampling.

The pronounced, and often readily visible, patchiness of the plankton distribution made a sampling program which would "average out" these differences highly desirable. The collection of large numbers of point samples for separate analysis was economically unfeasable, and the mixing of separate point samples after collection was considered impractical. Therefore the collections were made by pumping continuously from a predetermined depth (40 cm) while traveling along transects which were approximately the mid-line of each segment (Figure 2). When the boat could not pass under the bridge in the causeway between transects J and K, point samples were taken from either the end of a dock on the west side of the K region [K(D)] or from the flow passing under the bridge [K(RR)].

The pumped sample was mixed at the end of each transect and poured into a jug to be later subsampled for plankton, conductivity, orthophosphate, total phosphate, nitrate, attenuation coefficient, chlorophyll a, seston, and particulate carbon. The Secchi disc depth and surface temperature were determined at the start and end of each transect and the two values averaged.

Attenuation coefficient (alpha) to light at 515 nm wavelength was determined by measuring total attenuation (scattering plus absorption) of a collimated beam of light passing through 20 cm of water, and expressed in meters (alpha = $\ln (I_o/I_d)/D$, where I_o is the intensity of light after passing through D meters of pure water, and I_d is the intensity of light after passing through D meters of sample water).

All storage of subsamples was in polyethylene bottles. The 30 ml subsample for plankton analysis was preserved with enough Lugol's iodine in 10% acetic acid to give a gold color. The conductivity subsample was kept (unpreserved) in a 250 ml bottle until the measurement was made. The orthophosphate sample was filtered through No. 24 Schleicher & Schuell glass fiber filter paper held in a stainless steel Millipore Filter assembly, then poured into an unused or acid-washed 250 ml bottle; the total phosphate subsample not filtered. Both phosphate subsamples were preserved with 1.25 ml chloroform in 250 ml sample. A 500 ml unfiltered subsample was preserved with 0.4 ml concentrated sulfuric acid for nitrate determination. Water samples for chemical analysis were frozen upon return to Seattle.

All the following filtrations employed a 1 inch Millipore Filter assembly and 1/2 atmosphere vacuum. A chlorophyll sample was obtained by filtering a known quantity of sample through a 24 mm Reeve-Angel No. 934AH glass fiber filter, adding 3 drops of 1% Magnesium carbonate suspension near the end of filtration. The filter was folded and placed in an envelope, which was placed in a vacuum dessicator. A seston sample was obtained by filtering

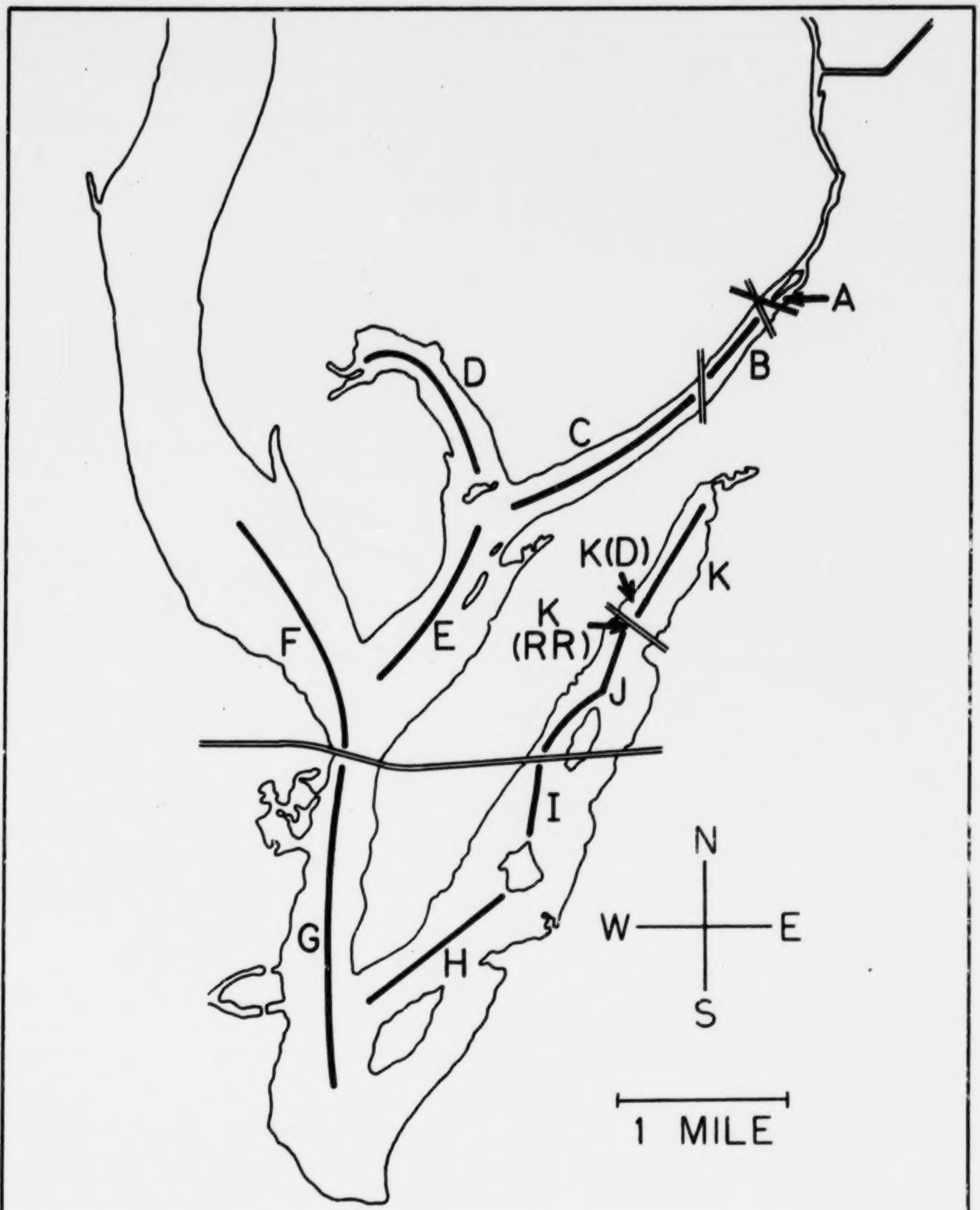

A
B
C
D
E
F
G
H
I
J
K
K(D)
K
(RR)
N
W
E
S
1 MILE

Figure 2. Plan of Moses Lake, showing sampling transects.

a known quantity of sample through a tared (to the nearest 0.01 mg) 24 mm Whatman GF/C glass fiber filter. A particulate carbon sample was obtained using an untared Whatman GF/C filter. All filters were placed in a freezer, inside their desiccator, upon returning to Seattle.

Chemical Analyses

Chlorophyll on the filters were analyzed by the flourometric method of Strickland and Parsons (5), using a tissue grinder, and without overnight soaking. The fluorometer was calibrated against spectrophotometric determinations with pure chlorophyll a in 10 cm cuvettes.

Total seston was determined by reweighing the filters to the nearest 0.01 mg on a Cahn Gram Electrobalance. The filters were then placed in 5 cm petri dishes, combusted at 500-600C for 1/2 hour, cooled, and reweighed to the nearest 0.01 mg again to determine the combustible fraction.

The remainder of the analyses followed procedures given by the American Public Health Association (6). Particulate carbon on the filters was determined by wet ashing in chromic acid and back-titrating the surplus dichromate ion with ferrous ammonium sulfate (COD determination). The method was calibrated against stock solutions of glucose. Conductivity was determined by a method using a conductivity bridge and dip-type conductivity cell. The readings were normalized to 25C. The cell/bridge combination was calibrated with standard stock potassium chloride solution. Orthophosphate and total phosphate were determined using the stannous chloride method while Nitrate was determined using the brucine method, both from the American Public Health Association (6).

Plankton Sample Analysis

The plankton samples were thoroughly shaken, and an aliquot placed in an examination chamber of one ml volume. The chamber consisted of a 2.00 cm diameter hole machined in an aluminum plate 0.318 cm thick, and sealed on the bottom with a 2.5 cm square No. 2 coverglass cemented over the hole with rubber cement. When the chamber was full, the top was covered with a second 2.5 cm square No. 2 coverglass and surplus sample was taken up with paper towel. The sample was allowed to settle for 15 minutes or longer, then the bottom was scanned in strips with a conventional compound microscope using 10X and 20X phase contrast objectives. The scanning was assisted by a square grid placed in the ocular. Species were tallied as they were encountered until five specimens (cells) were seen. A subjective judgement was made as to which were the predominant species and which were somewhat less abundant subpredominant species.

Plankton Data Analysis

In the analysis of the species occurrence data, each species was assigned a code number indicating its abundance in each sample. These were as follows:

0: Absent (not detected)

1: Present at less than 5 cells/ml

2: Present at 5 or more cells/ml

3: Subpredominant

4: Predominant

A computer program was written in Fortran IV (Appendix A) for the IBM 7040-7094 Direct-Coupled System at the University of Washington Computer Center, to do a numerico-taxonomic analysis (cluster analysis) of the species occurrence data. This was done in an effort to place the application of the indicator organism concept on a more objective and repeatable basis so that the organisms themselves might be employed to evaluate the prevailing living conditions in the various segments of Moses Lake. This subject is discussed in the manuscript authored by Buchanan and Lighthart which is attached (Appendix B). The procedures are briefly outlined below.

The abundance code for each species in a sample was punched in its assigned column in a data processing card representing that sample. The sequence of species in the cards (column number) corresponded to the sequence of a second set of cards (card number) which contained the species names. The sequence of sample data cards also corresponded to the sequence of a third set of cards containing the sample names. For the purposes of the numerico-taxonomic analysis the only species which were counted as "present" in a sample were those with code numbers 2, 3, or 4, (3 or 4 were considered equivalent to 2), and code number 1 was counted as "absent" (equivalent to 0).

The data cards, together with the computer programs, were fed to the computer, which read all the data into memory. The programs then processed the data in the following steps:

1) The computer compared the occurrence of all possible pairs of species in all the samples and calculated the frequency of occurrence of each taxon, the frequency of joint occurrence of all possible pairs, and an index of joint occurrence (distribution similarity index) for all possible pairs.[1] These results were written onto magnetic tape for further processing by a second program. Then the data were re-examined by the computer to calculate the number of taxa in each sample, the number of taxa all pairs of samples have in common, and an index[1] of biotic similarity between all possible sample pairs. Again, a magnetic tape was written for subsequent processing.

2) The second program read the tape containing joint occurrence indices and rearranged the sequence of species in an array so as to cluster together taxa which had mutually high joint occurrence indices. The rearranged ("clustered") array was printed out in a trellis diagram for examination. The computer then processed, in a similar way, the data on sample similarity, and printed it out in a trellis diagram.

When the trellis diagrams presenting the clustered species and samples were examined, the members of each cluster (group) were identified on the basis

---

[1] The index used in this case was defined as

$$FC = c/\sqrt{ab} - 1/(2\sqrt{b})$$

where c is the joint occurrence frequency, a is the frequency of species A, and b is the frequency of species B, and b > a.

of the similarity indices (figure 2). These groups could then be examined for physico-chemical correlations which might explain the biological distinctiveness of sample groups or the temporo-spatial distinctiveness of species groups.

To determine what correspondence, if any, there was between the two kinds of groups, the frequencies of occurrence of each member of the species groups was determined and tabulated for each sample group. The correspondences found were illustrated in a diagram showing three levels of correspondence: "low", "moderate", and "high".

To search for potentially significant correlations between physico-chemical factors and the sample groups, a Fortran IV program (Appendix A) was written to read the raw data associated with each sample and manipulate it as follows. The chemical and physical factors (including temperature, conductivity, Secchi disc depth, attenuation coefficient to 515 nm wavelength light [alpha], orthophosphate P, total phosphate P, and nitrate N) were tabulated for each sample. The biological data (including total seston, combustible seston, percent combustible seston, particulate carbon, chlorophyll a, acid factor, total seston/alpha ratio, combustible seston/alpha ratio, and particulate carbon/alpha ratio) were tabulated for each sample. Finally, a statistical summary of all samples in the sample group was tabulated for each measured factor mentioned above. The table included the number of samples for which measurements were made, the mean of those samples, the standard deviation, and the coefficient of variation.

Submitting each of the sample groups to this program separately enabled the groups to be characterized with respect to those factors for which data were available.

The sample groups were submitted to a computerized analysis of their biological characteristics by means of a special Fortran IV program (Appendix A) designed to work with the same data used for the cluster analysis. This program read the species occurrence data for each batch of samples and printed a table with the following information:

1) Taxon name
2) Frequency of detection at any abundance level
3) Frequency of occurrence at 5 or more cells/ml
4) Number of taxa detected in the sample group
5) Number of taxa present at 5 or more cells/ml in the sample group

The tables generated by this program for each sample group enabled preparation of a table summarizing the taxonomic spectra of all sample groups.

The spatial distributions of the sample groups (biotic community types) for each collection occasion were illustrated by plotting on a separate map for each occasion, the group number to which the sample from each transect belonged. A summary of the entire series of collections was made in tabular form.

Plankton Experiments

Experiments were conducted in situ during 1969 to determine the effect of low-nutrient Columbia River dilution water, as well as the effect of "lake conditioning" of inflow water on growth of nuisance algae. Two experiments were conducted on each aspect, one using plastic bags .78 m diameter and 2.8 m deep, the other three in 2.5 gallon transparent water jugs suspended immediately beneath the surface.

In the initial dilution experiment reported on here, low-nutrient water was added to bags to produce final concentrations of 100, 90, 86 and 61 percent lake water. In the lake water conditioning studies, lake algae were inoculated into water collected from an influent stream and four downstream points in the lake (Parker Horn) following filtration through 0.5-1.0 μ pore size filters. Water samples were collected every two days from all containers, in addition to a lake control, for approximately 2 weeks and analyzed for chlorophyll a content and species composition. Gross productivity measurements were made in the initial dilution experiment. Nutrient content (N and P) was determined usually at the beginning and end of the experimental periods. To control for the effect of algal cell dilution against dilution of only nutrients, lake water, filtered through a 100 μ net to remove nuisance algae, was added to a replicate 50% solution. In the case of the initial dilution experiment, the unfiltered water concentration was 54%.

Monitor Data Evaluation

Automatic water quality monitors were installed in late 1968, but did not become fully operative until summer of 1969. The sensor, analyzer and recording units were placed on shore and water from two feet below the surface and two feet above the lake bottom was supplied to the units by pumps suspended from a raft anchored about 300 feet offshore. Diurnal light-bottle and dark-bottle oxygen change studies were conducted several times during the summer in an attempt to correlate measured productivity (bottle method) with estimates from in situ change in oxygen content.

In addition to continuous monitoring of oxygen, temperature, pH and conductivity, vertical profile of chlorophyll a and LB-DB oxygen measurements were made every 2 hours on several occasions. Only data from three dates will be reported on here due to a shortage of time for data analysis.

Hydraulic

Topography

An integral part of the initial proposal was the design of a physical hydraulic model of those sections of Moses Lake of concern in the study of the feasibility of flushing operations. Accordingly, effort was devoted during the summer of 1968 to mapping the topography of Parker Horn. Work was confined to the area upstream from the junction of Parker Horn and Lewis Horn.

Baselines were laid out on shore using theodolites and direct taping of distances. The baseline net was tied in with existing USBR control points. Bottom contours were taken at a number of cross-sections in Parker Horn; bottom profiles were obtained by direct hand-line soundings from a boat positioned along a predetermined line, with the boat location determined in some cases by triangulation and in others by stadia readings on a rod held stationary at the boat position. Depth readings were correlated with lake levels recorded at the USGS (United States Geological Survey) gage, "Moses Lake at Moses Lake, Washington," located on the north side of the highway embankment at the east end of the Interstate Highway 90 crossing of Moses Lake, so that bottom contour elevations could be referred to datum. Cross-sections were also measured at the three bridge crossings on Parker Horn. Data have been incorporated in a map of Parker Horn (portions of this map are incorporated in the present report) which will provide adequate topographical data for constructing a physical model of Parker Horn.

Hydraulic

Hydraulic measurements were directed toward partial determination of the water budget for Parker Horn or toward determination of current patterns in parts of Parker Horn. A limited amount of stream gaging was done on the Rocky Coulee Wasteway, using a conventional Price meter. Water velocities measured at all stations on Parker Horn, including those at channel constrictions at the three bridges on the 'horn', were too low for accurate measurement by a Price-type meter, and the three techniques described below were used for quantitative determination of water movement.

1) Current meters. The meter used was the French-made Neyrpic "Midget Current Meter", designed for use where velocities and/or flow cross-sections are small. A raised semicylinder on the shaft of the 4-cm 4-pale propellor varies the electrical resistance through the water between two electrodes, causing a battery powered counter circuit to tally the revolutions on an odometer dial. The deck unit contains the dial counter and a standard stop watch. The propeller used is calibrated over the range of 0.033-3.3 feet per second.

   The Neyrpic meter records the total number of revolutions, independent of direction, so that the device cannot be used in oscillating flows of short periods or to determine direction of flow. Vanes which orient conventional current meters into the local flow direction would be ineffective in the low velocities encountered in Moses Lake. Accordingly, a battery operated "F-T-S" meter produced in the Developmental Laboratory of the Department of Oceanography, University of Washington, was used to determine flow direction. (This capability was required because of the possibility of reverse currents in a vertical profile due to effects of stratification and/or wind-driven surface currents). The meter uses a light source, light pipes, and two photocells placed in a stationary head opposite a white-striped cylindrical band fitted to the perimeter of a Neyrpic propellor; the direction of flow is indicated by a milliameter in the deck unit and is determined by the photocell first receiving reflected light from a passing oblique stripe on the rotor. Circuitry of this meter was still in the developmental stages, and as a result the device was used for directional sensing only.

   For field use in which most measurements were taken from a small, anchored skiff, the two current meters were mounted on a 5/8-inch square aluminum hollow tube, which in turn was attached to a 1-inch aluminum pipe in such a way that the instruments could be raised and lowered while the pipe, with a plastic base plate, remained planted on the bottom. The Neyrpic meter was situated one foot above the directional meter; speed and direction readings were taken at one-foot intervals, with bottom current direction only being recorded.

2) Drogues. Drogues were used for pathline determinations in various parts of Parker Horn. The design used incorporated 8-inch high by 14-inch wide crossed plywood vanes attached to a piece of 2-inch PVC pipe capped at the bottom and weighted with lead to overcome buoyancy. Different pipe lengths were used to adapt to the range of water depths in various parts of Parker Horn. The vanes were set at the desired depth below water surface by adjusting the level at which they were clamped to the pipe and/or by varying the lead ballast in the PVC pipe. A block of painted styrofoam (made small to minimize possible wind drag) was placed over the top of the pipe protruding above the water surface to provide visibility. Drogue paths were determined by triangulation, with the drogue location fixed by instantaneous angle readings from two transits set up on a baseline on the shore.

3) Dye. Rhodamine B dye was used as the tracer in all dye studies. All dye studies made were of the single insertion type. Preliminary studies conducted during the summer of 1968 provided visual indication of gross flow patterns, these latter obtained through aerial observations. Tests in the upper basin of Parker Horn during 1969 had the objective of determining travel times through that basin, and a limited number of tests in the main basin of Parker Horn in 1969 were aimed at providing some information on flushing times.

All dye study results were formulated in terms of relative dye concentration vs. time at a particular station, or stations. Most data are based on samples taken from prescribed water depths at the station. The individual grab samples were taken with a length of plastic tubing, placed in labeled test tubes, capped, and stored in covered boxes providing protection from light until the dye concentration readings were made in the laboratory within the next two days. A Turner Model 110 Fluorometer was used, with fluorescence indicating dye concentrations. As relative concentrations only were desired, no attempt was made to determine actual concentrations.

RESULTS

Biological

Plankton Community Analyses

The 173 plankton samples collected between July 30, 1968 and May 22, 1969 yielded a total of 111 taxa, in 10 classes, of algae and protozoa. The complete list is given in Table II and taxonomic notes are presented in

TABLE II.

COMPLETE LIST OF ORGANISMS FOUND IN MOSES LAKE PLANKTON SAMPLES.
(DOUBLE ASTERISKS INDICATE THOSE ORGANISMS NOT USED IN THE CLUSTER ANALYSES)

CHLOROPHYCEAE

ACANTHOSPHAE. ZACHARIASI **
ACTINASTRUM GRACILLIMUM
ANKISTRODESMUS FALCATUS
CHODATELLA LONGISETA
CHODATELLA SUBSALSA
CLOSTERIOPSIS LONGISSIMA
CLOSTERIUM ACEROSUM **
CLOSTERIUM POLYSTICTUM **
COELASTRUM SPHAERICUM
COSMARIUM BIOCULATUM
COSMARIUM PROTRACTUM
COSMARIUM PUNCTULATUM
CRUCIGENIA QUADRATA
CRUCIGENIA RECTANGULARIS
CRUCIGENIA TETRAPEDIA
DICTYOSPHAER. PULCHELLUM
DIMORPHOCOCCUS SP. 1
ECHINOSPHAERE. LIMNETICA **
ELAKATOTHRIX GELATINOSA
FRANCEIA DROESCHERI **
MICRACTINIUM CF. PUSILLUM
OOCYSTIS LACUSTRIS
PANDORINA MORUM
PEDIASTRUM BORYANUM
PEDIASTRUM DUPLEX
PEDIASTRUM SIMPLEX
PEDIASTRUM TETRAS
SCENEDESMUS ACUMINATUS
SCENEDESMUS BIJUGA
SCENEDESMUS QUADRICAUDA
SCHROEDERIA ANCORA
SCHROEDERIA SETIGERA
SELENASTRUM SP. 1
SPHAEROCYSTIS SCHROETERI
SPIROGYRA CRASSA
SPONDYLOSUM CF. PULCHRUM **
STAURASTRUM PARADOXUM
TETRAEDRON CAUDATUM
TETRAEDRON HASTATUM **
TETRAEDRON MINIMUM
TETRAEDRON MUTICUM
TETRAEDRON REGULARE **
TETRAEDRON TRIGONUM **
TREUBARIA CRASSISPINA **
TREUBAR.TRIAPPENDICULATA
TROCHISCIA OBTUSA (Q) **
UNIDENT. -COCCOMYXACEAE-

TABLE II (CONTINUED)

EUGLENOPHYCEAE

EUGLENA SP. 1

BACILLARIOPHYCEAE

AMPHORA OVALIS
ASTERIONELLA FORMOSA
CYCLOTELLA MENEGHINIANA
CYMATOPLEURA SOLEA
CYMBELLA CF. TUMIDA **
CYMBELLA TURGIDA
CYMBELLA SP. 1 **
DIATOMA VULGARE
EPITHEMIA TURGIDA **
FRAGILARIA CF. CAPUCINA
FRAGILARIA CONSTRUENS
FRAGILARIA CROTONENSIS
GOMPHONEMA SP. 1 **
GOMPHONEMA SP. 2
MELOSIRA GRANULATA
MELOSIRA VARIANS
MELOSIRA SP. 1
NAVICULA SP. 1
NAVICULA SP. 2
NAVICULA SP. 3
NITZSCHIA ACICULARIS
NITZSCHIA CF. LINEARIS
NITZSCHIA VERMICULARIS
NITZSCHIA SP. 1
RHOICOSPHENIA CURVATA **
STEPHANODISCUS NIAGARAE
SURIRELLA OVATA
SYNEDRA ARCUATA
BICOECA CRYSTALLINA

CHRYSOPHYCEAE

BICOECA LACUSTRIS
BICOECA CF.MULTIANNULATA
BICOECA SP. 1
CODOMONAS ANNULATA (Q) **
DINOBRYON DIVERGENS **
MALLOMONAS SP. 1
MALLOMONAS SP. 2
MONOSIGA SP. 1
PSEUDOPEDINELLA SP. 1 **
RHIZOCHRYSIS LIMNETICA **
SALPINGO. FREQUENTISSIMA
SALPINGOECA SP. 1 **

TABLE II (CONTINUED)

XANTHOPHYCEAE

OPHIOCYTIUM CAPITATUM **

DINOPHYCEAE

CERATIUM HIRUNDINELLA
PERIDINIUM SP. 1

CRYPTOPHYCEAE

CRYPTOMONAS CF. OVATA
CRYPTOMONAS CF.OBOVOIDEA
CRYPTOMONAS SP. 1

CYANOPHYCEAE

ANABAENA CIRCINALIS
APHANIZOMENO. HOLSATICUM
COELOSPHAERI. NAEGLIANUM
GOMPHOSPHAERI. LACUSTRIS
MICROCYSTIS AERUGINOSA
MICROCYSTIS SP. 1
OSCILLATORIA SP. 1

CILIATEA

CODONELLA CRATERA
STROMBIDIUM SULCATUM
STROMBIDIUM SP. 1 **
TINTINNOPSIS CYLINDRATA
VORTICELLA SP. 1
UNIDENTIFIED COLEPIDAE
UNIDENT. OLIGOTRICHIDA

SARCODINA

ELAEORHANIS OCULEA (Q) **

MISCELLANEOUS

UNIDENTIFIED COLONIAL 1

Appendix C. Of the total 111 taxa, 24 occurred in concentrations of 5 or more cells/ml too rarely (or not at all) to be useful in the numerico-taxonomic treatment. These taxa are marked with asterisks in Table II.

Cluster Analysis

Table III presents the sample groups which emerged from the clustering operations; an example of the trellis diagrams generated by the computer (redrawn, representing similarity index ranges by intensity of shading) is shown in Figure 3. This example, based on odd-numbered samples when samples were ranked in order of collection, shows the seven sample groups which emerged when all samples were treated. Figure 4 summarizes the intragroup and intergroup similarities among these seven sample groups.

The clustering of species yielded eight species groups, whose members are presented in Table IV along with the frequencies of occurrence of each species in the sample groups. The intragroup and intergroup similarities for species are summarized in Figure 5. In this case the intragroup similarities (consistancy of joint occurrence of group members) were usually quite low; only in the case of the group consisting of almost ubiquitous species (group 7), and two other cases, were members of species groups highly consistent in joint occurrence.

The correspondence between sample groups and species groups, as derived from the data presented in Table IV, is illustrated in Figure 6. It is notable that three sample groups had no species group corresponding to them, while some others had more than one species group corresponding to them. This is because the biota which characterize a sample group may have more than one major subset, and these subsets may occur independently of each other; on the other hand, a sample group may be characterized by an exceptionally variable biota (a "catch-all" group) or by organisms which occur too rarely to have high joint occurrence indices (in which case species clustering based upon high indices does not necessarily place them in a cluster together).

The mapped spatial distributions of the sample groups (biotic community types) for each collection occasion are shown on the continued pages of Figure 3. The entire temporo-spatial distribution pattern for all samples is summarized in Table VIII.

Notes on the Characteristics of Sample Groups

The following notes on the sample groups are meant to draw attention to important features of the data presented in Tables III, V, VI and VII, and Figure 4. Because there were so few samples in group 7, little confidence can be placed in statistical analyses of these data.

Sample Group 1

: - 24 samples from J, K in August-May.

: - One of the least variable groups, being the most uniform with
respect to 1) Total seston
2) Combustible seston
3) Percent combustible seston
4) Particulate carbon/alpha ratio

: - Highest mean conductivity of all groups, but also most variable conductivity of all groups. The mean values for this group were

TABLE III.

LISTING OF SAMPLES IN THE SAMPLE GROUPS IDENTIFIED AMONG THE 173 SAMPLES COLLECTED FROM MOSES LAKE, WASHINGTON, FROM JULY 30, 1968 TO MAY 22, 1969.

GROUP 1.

J 9 AUG., 1968
J 16 AUG., 1968
J 23 AUG., 1968
J 30 AUG., 1968
J 17 SEPT., 1968
J 24 SEPT., 1968
J 12 OCT., 1968
J 26 OCT., 1968
J 9 NOV., 1968
J 14 DEC., 1968
J 26 APRIL, 1969
J 10 MAY, 1969
J 22 MAY, 1969
K 9 AUG., 1968
K 16 AUG., 1968
K 23 AUG., 1968
K 30 AUG., 1968
K 17 SEPT., 1968
K 12 OCT., 1968
K 26 OCT., 1968
K 9 NOV., 1968
K(RR) 22 NOV., 1968
K(RR) 14 DEC., 1968
K 27 MARCH, 1969
K(RR) 11 APRIL, 1969
K(D) 26 APRIL, 1969
K(RR) 10 MAY, 1969
K(RR) 22 MAY, 1969

GROUP 2.

D 14 DEC., 1968
E 14 DEC., 1968
F 12 OCT., 1968
F 26 OCT., 1968
F 9 NOV., 1968
F 14 DEC., 1968
F 26 APRIL, 1969
G 12 OCT., 1968
G 26 OCT., 1968
G 9 NOV., 1968
G 14 DEC., 1968
H 14 DEC., 1968

TABLE III (CONTINUED)

GROUP 3.

D 12 OCT., 1968
D 26 OCT., 1968
D 9 NOV., 1968
E 12 OCT., 1968
E 26 OCT., 1968
E 9 NOV., 1968
F 10 MAY, 1969
F 22 MAY, 1969
G 26 APRIL, 1969
G 10 MAY, 1969
G 22 MAY, 1969
H 9 NOV., 1968
H 27 MARCH, 1969
H 11 APRIL, 1969
H 26 APRIL, 1969
H 10 MAY, 1969
H 22 MAY, 1969
I 14 DEC., 1968
I 11 APRIL, 1969
I 27 MARCH, 1969
I 26 APRIL, 1969
I 10 MAY, 1969
I 22 MAY, 1969
J 27 MARCH, 1969
J 11 APRIL, 1969

GROUP 4.

D 26 APRIL, 1969
E 26 APRIL, 1969
F 27 MARCH, 1969
F 11 APRIL, 1969
G 27 MARCH, 1969
G 11 APRIL, 1969

GROUP 5.

C 30 JULY, 1968
C 9 AUG., 1968
C 16 AUG., 1968
C 23 AUG., 1968
C 30 AUG., 1968
D 30 JULY, 1968
D 9 AUG., 1968
D 16 AUG., 1968
D 23 AUG., 1968
D 30 AUG., 1968
D 17 SEPT., 1968
D 24 SEPT., 1968
E 1 AUG., 1968
E 9 AUG., 1968
E 16 AUG., 1968
E 23 AUG., 1968

TABLE III (CONTINUED)

GROUP 5 (CONTINUED).

E 30 AUG., 1968
E 17 SEPT., 1968
E 24 SEPT., 1968
F 9 AUG., 1968
F 16 AUG., 1968
F 23 AUG., 1968
F 30 AUG., 1968
F 17 SEPT., 1968
F 24 SEPT., 1968
G 9 AUG., 1968
G 16 AUG., 1968
G 23 AUG., 1968
G 30 AUG., 1968
G 17 SEPT., 1968
G 24 SEPT., 1968
H 9 AUG., 1968
H 16 AUG., 1968
H 23 AUG., 1968
H 30 AUG., 1968
H 17 SEPT., 1968
H 24 SEPT., 1968
H 12 OCT., 1968
H 26 OCT., 1968
I 9 AUG., 1968
I 16 AUG., 1968
I 23 AUG., 1968
I 30 AUG., 1968
I 17 SEPT., 1968
I 24 SEPT., 1968
I 12 OCT., 1968
I 26 OCT., 1968
I 9 NOV., 1968

GROUP 6.

A 31 JULY, 1968
A 9 AUG., 1968
A 16 AUG., 1968
A 23 AUG., 1968
A 30 AUG., 1968
A 17 SEPT., 1968
A 24 SEPT., 1968
A 12 OCT., 1968
A 26 OCT., 1968
A 9 NOV., 1968
A 22 NOV., 1968
A 14 DEC., 1968
A 11 APRIL, 1969
A 25 APRIL, 1969
A 10 MAY, 1969
A 22 MAY, 1969
B 9 AUG., 1968
B 16 AUG., 1968
B 23 AUG., 1968

TABLE III (CONTINUED)

GROUP 6 (CONTINUED).

B 30 AUG., 1968
B 17 SEPT., 1968
B 24 SEPT., 1968
B 12 OCT., 1968
B 26 OCT., 1968
B 9 NOV., 1968
B 22 NOV., 1968
B 14 DEC., 1968
B 11 APRIL, 1969
B 26 APRIL, 1969
B 10 MAY, 1969
B 22 MAY, 1969
C 17 SEPT., 1968
C 24 SEPT., 1968
C 12 OCT., 1968
C 26 OCT., 1968
C 9 NOV., 1968
C 22 NOV., 1968
C 14 DEC., 1968
C 11 APRIL, 1969
C 26 APRIL, 1969
C 10 MAY, 1969
C 22 MAY, 1969
D 22 NOV., 1968
D 27 MARCH, 1969
D 11 APRIL, 1969
D 10 MAY. 1969
D 22 MAY, 1969
E 27 MARCH, 1969
E 11 APRIL, 1969
E 10 MAY, 1969
E 22 MAY. 1969

GROUP 7.

A 26 MARCH, 1969
B 26 MARCH, 1969
C 26 MARCH, 1969

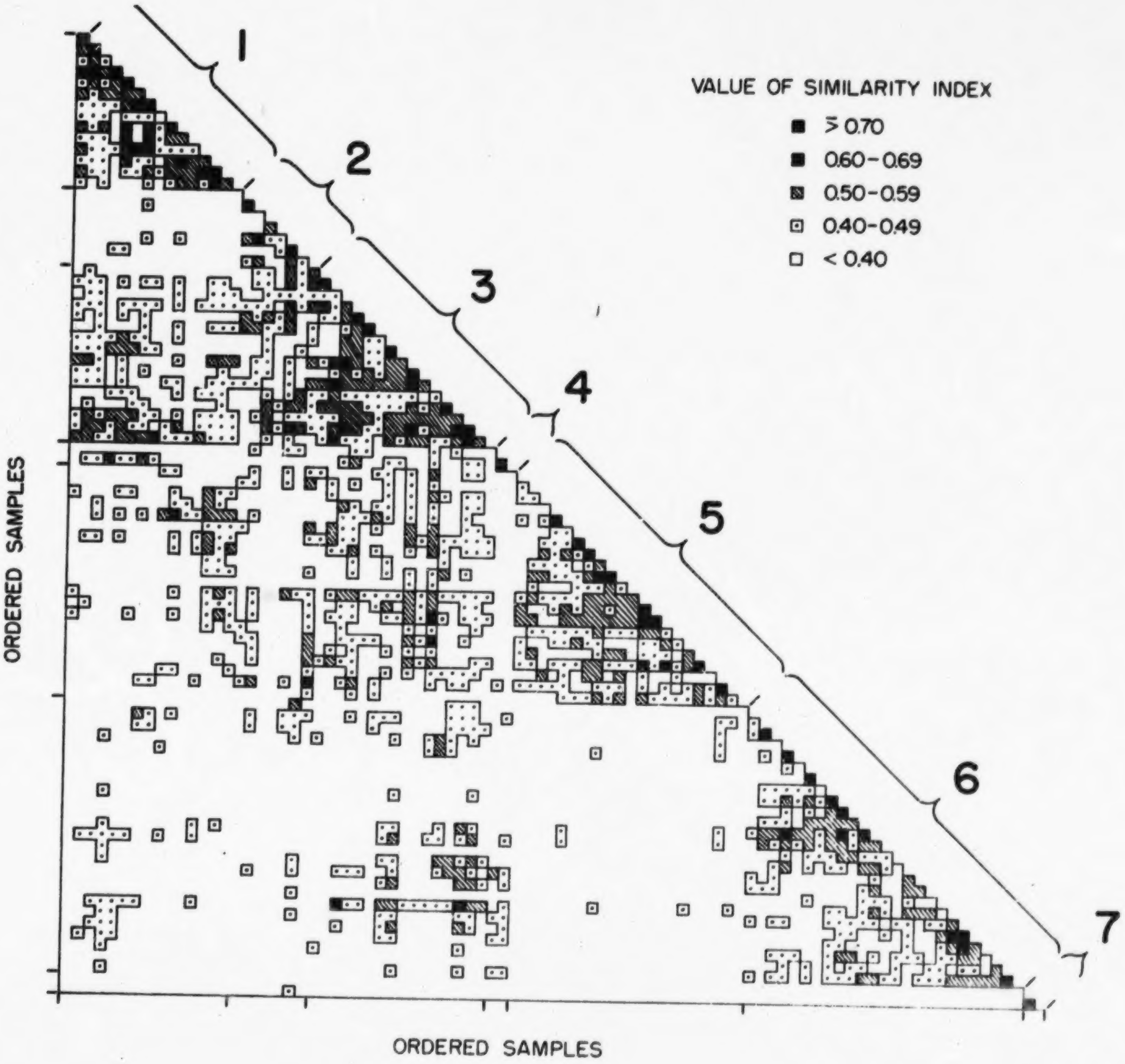


Figure 3. Trellis diagram of half the Moses Lake samples collected between July 30, 1968 and May 22, 1969 (every odd-numbered sample when ranked in order of collection) after cluster analysis. The distribution of these sample groups throughout the lake and with time are shown on accompanying maps of the lake.

Figure 3 (Continued). July 30 - August 1, 1968

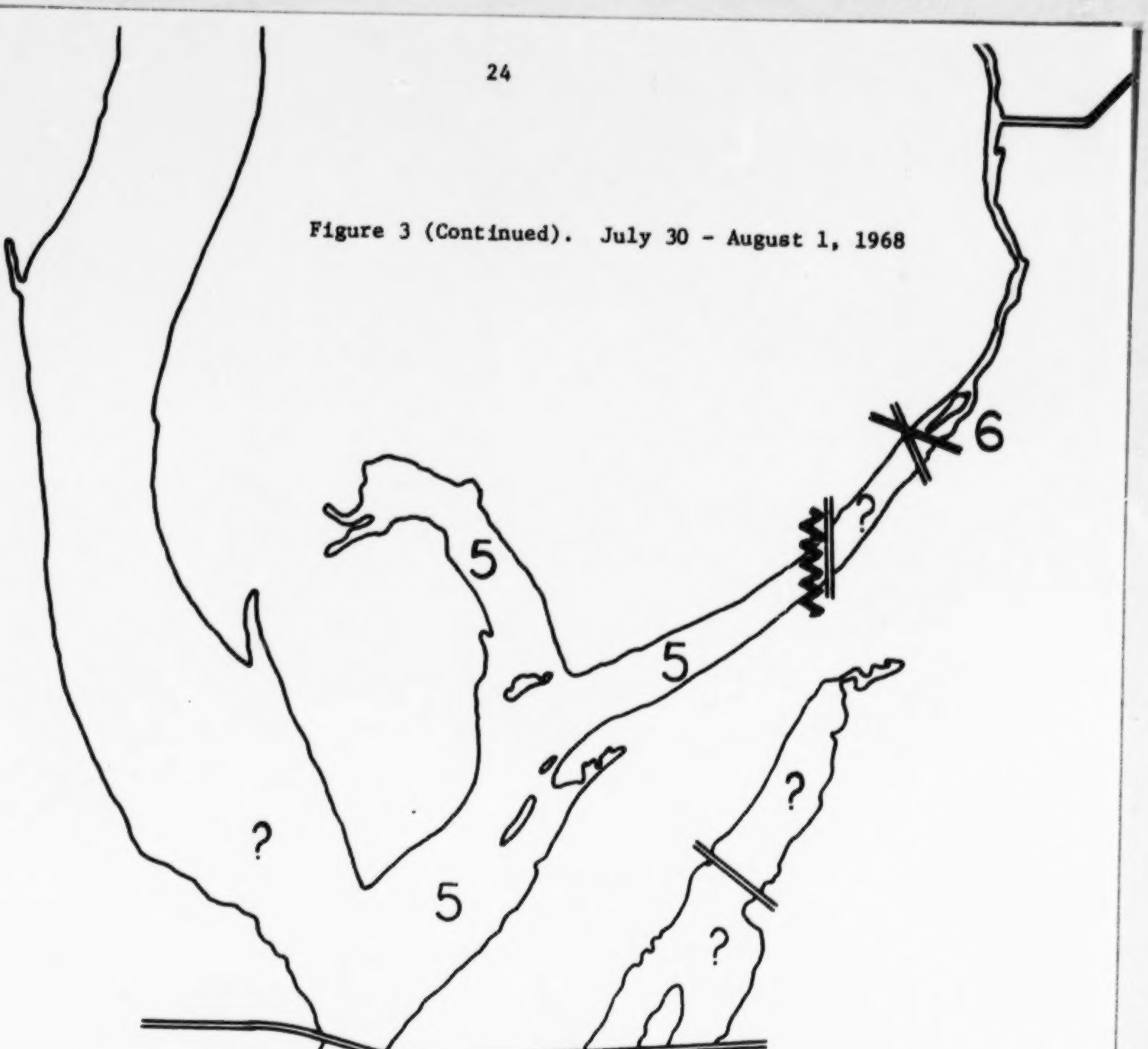

5
5
5
?
?
6
?
?
?
?
?
?
N
W
E
S
1 MILE

Figure 3 (Continued). August 9-10, 1968

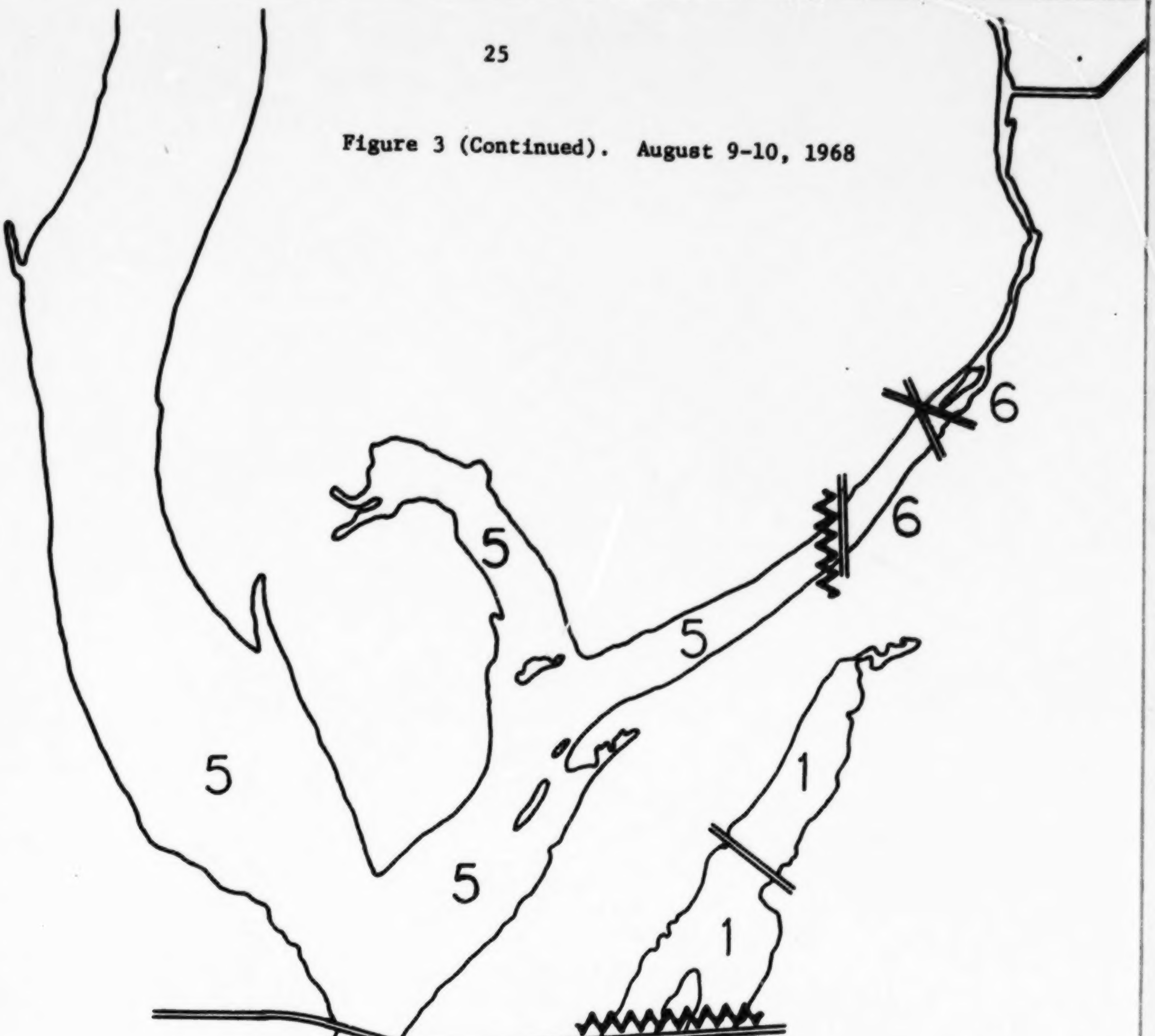

6
6
5
5
5
1
1
5
5
5
5
N
W
E
S
1 MILE

Figure 3 (Continued). August 16-17, 1968

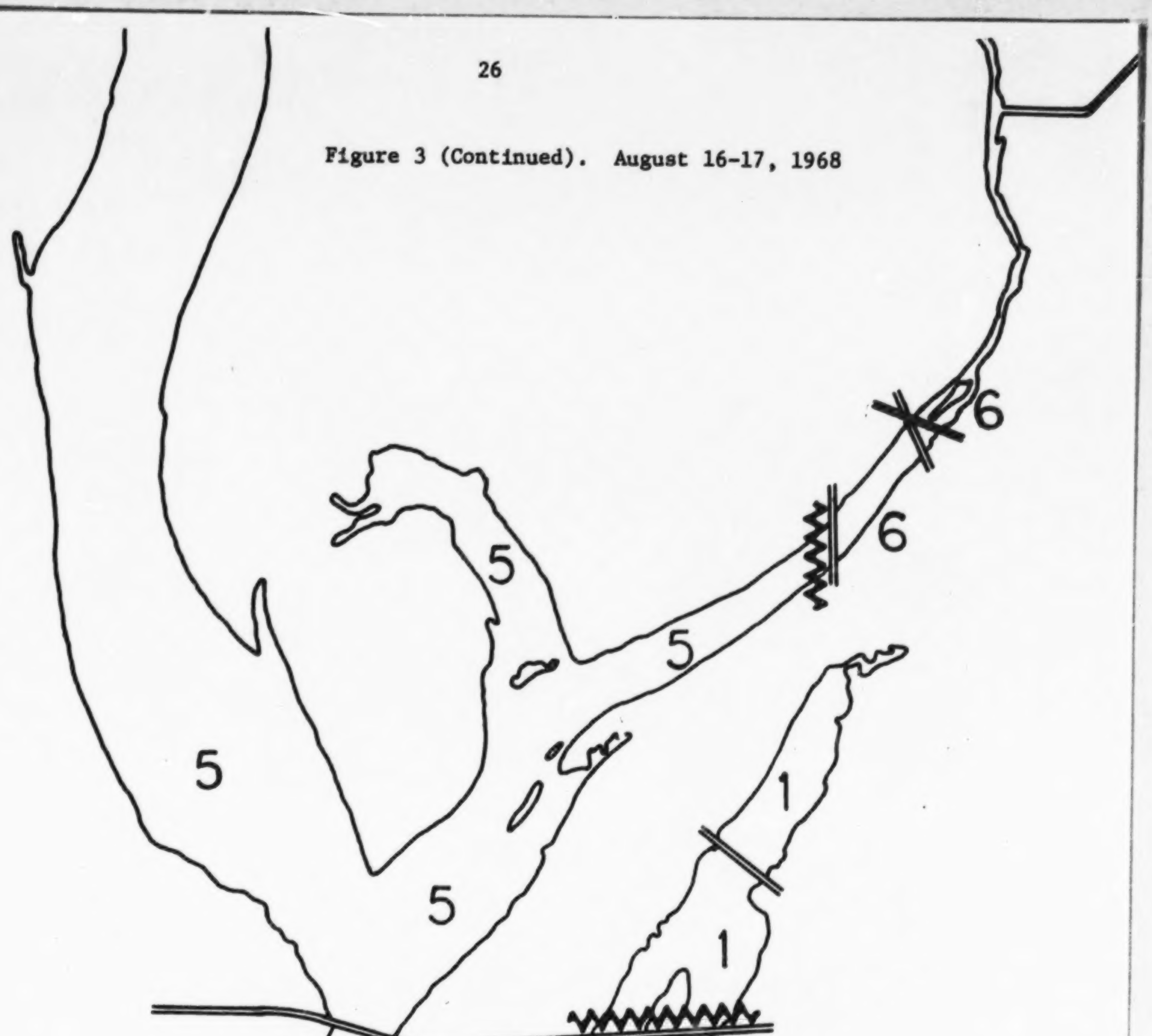

6
6
5
5
5
1
5
1
5
N
W
E
5
S
5
1 MILE

Figure 3 (Continued). August 23-24, 1968

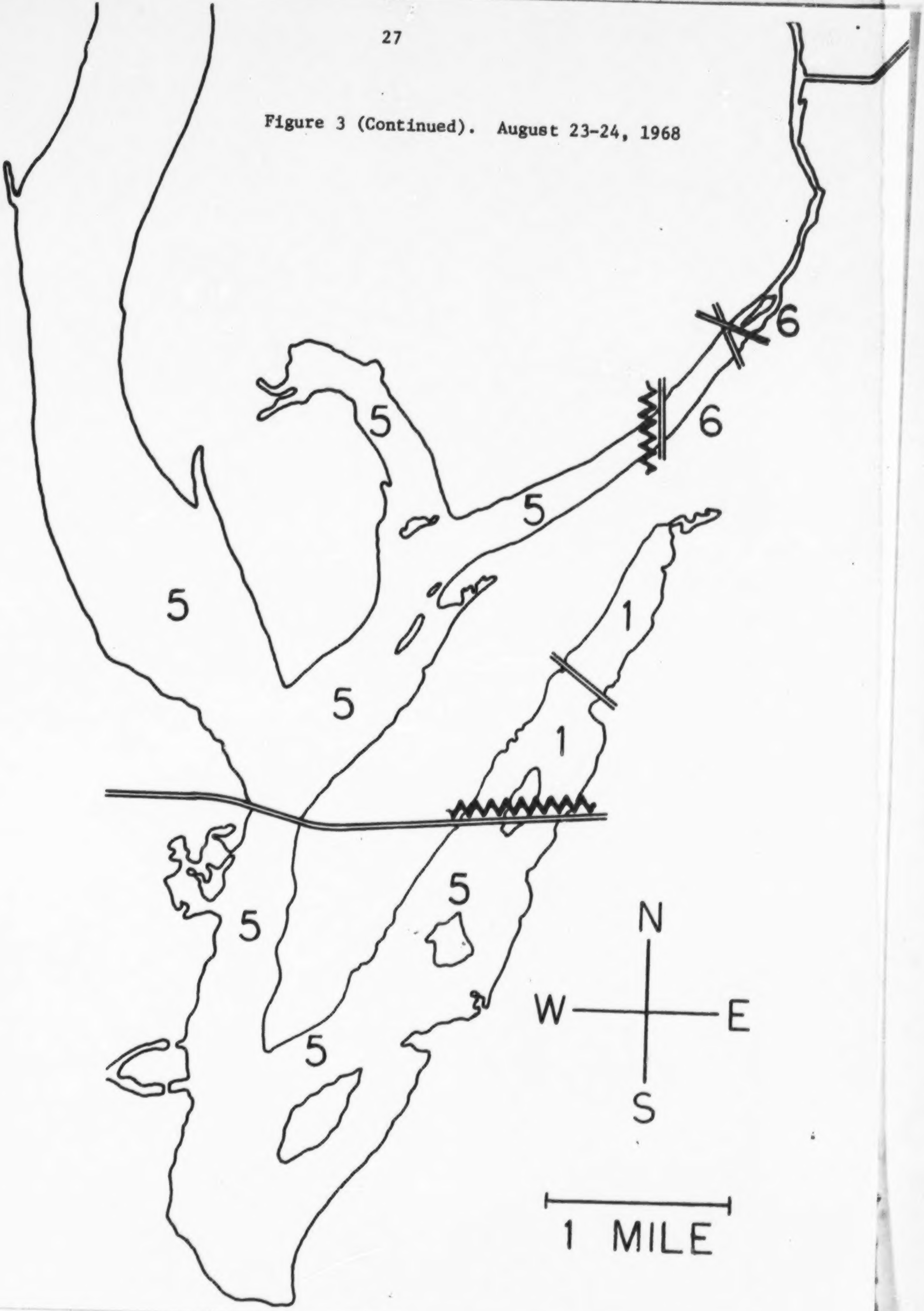

6
6
5
5
5
1
1
5
5
5
5
N
W
E
S
1 MILE

Figure 3 (Continued). August 30-31, 1968

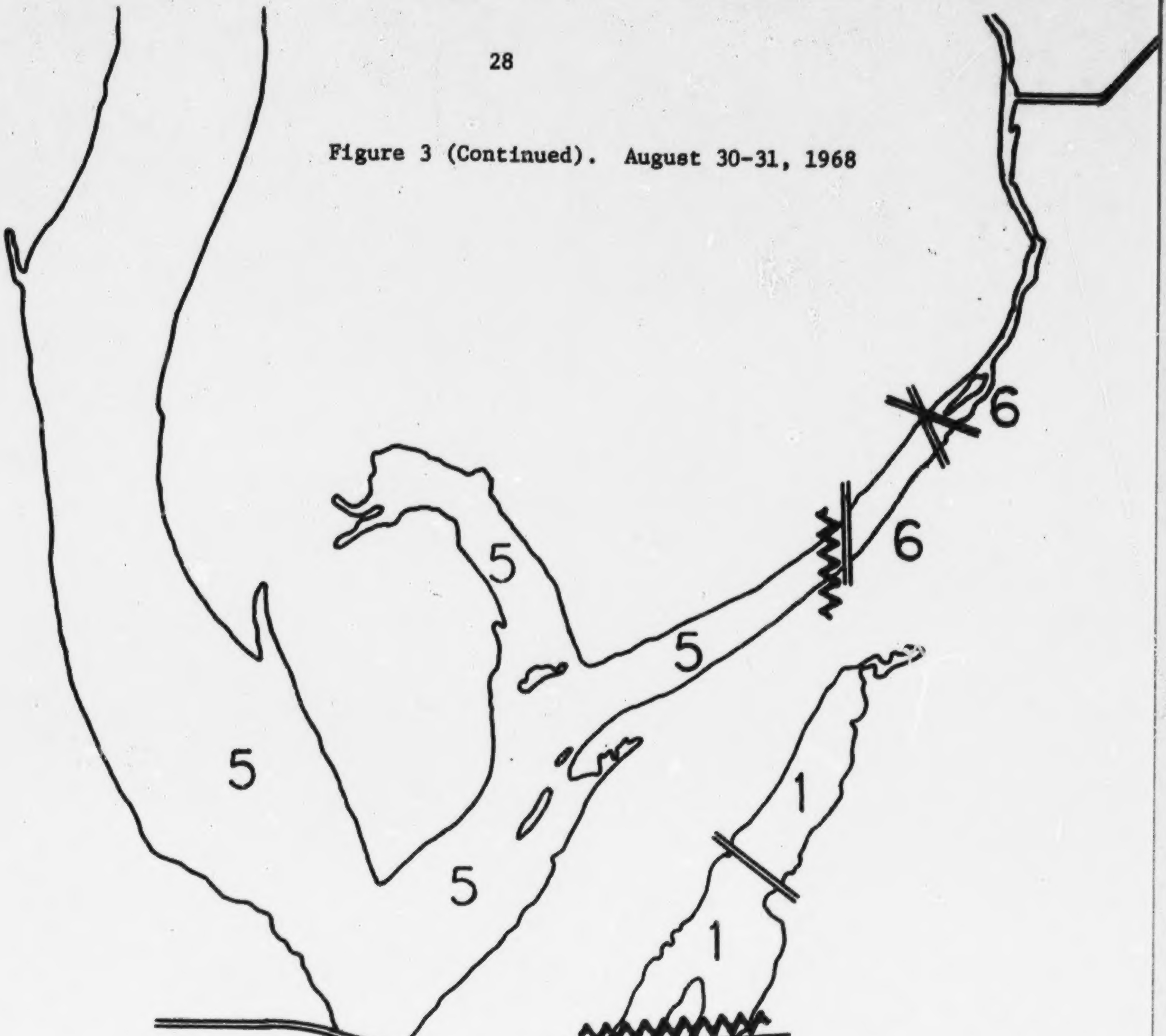

6
6
5
5
5
1
1
5
N
W
E
S
5
5
1 MILE

Figure 3 (Continued). September 17-18, 1968

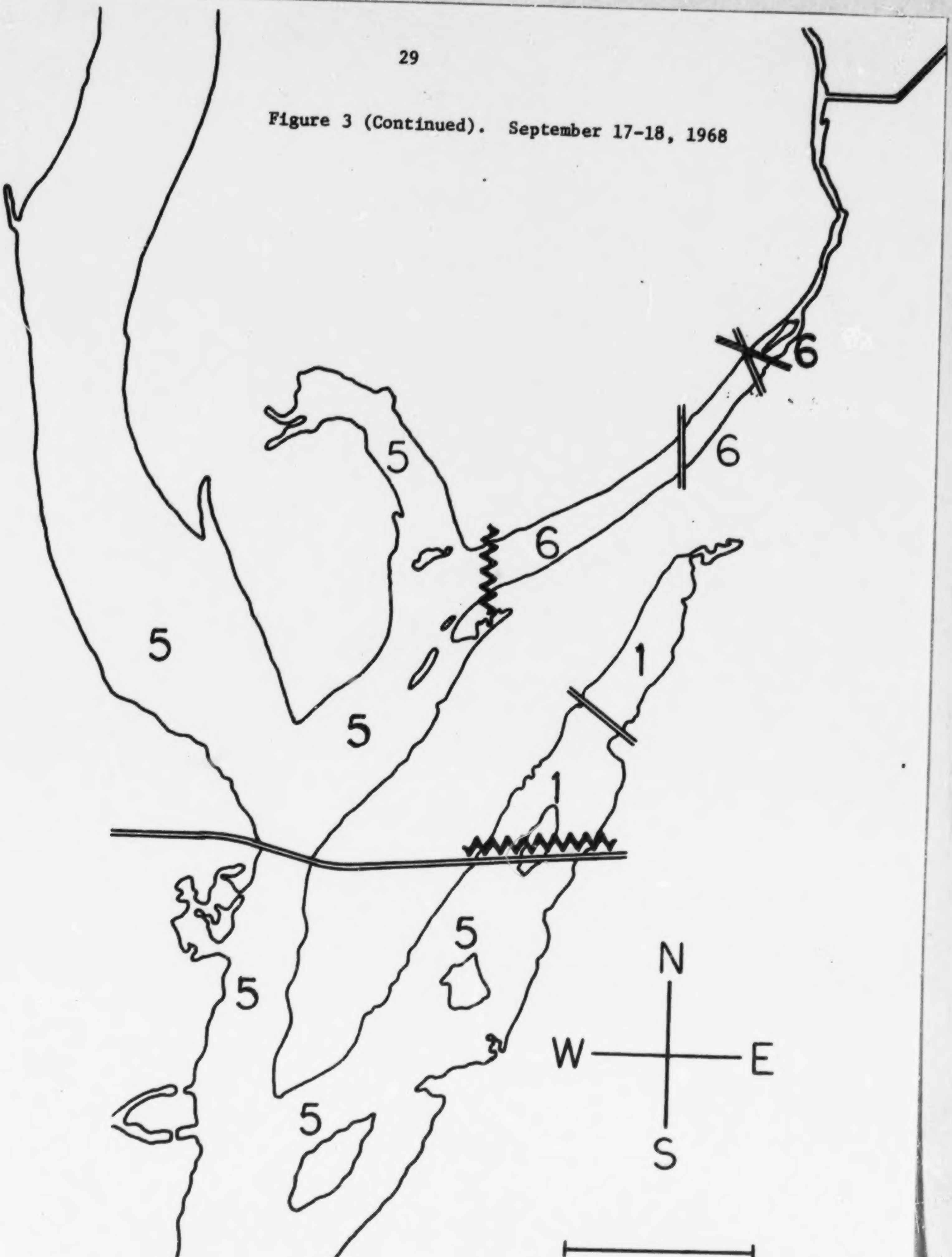

5
5
5
6
6
6
5
1
1
5
5
5
N
W
E
S
1 MILE

Figure 3 (Continued). September 24-25, 1968

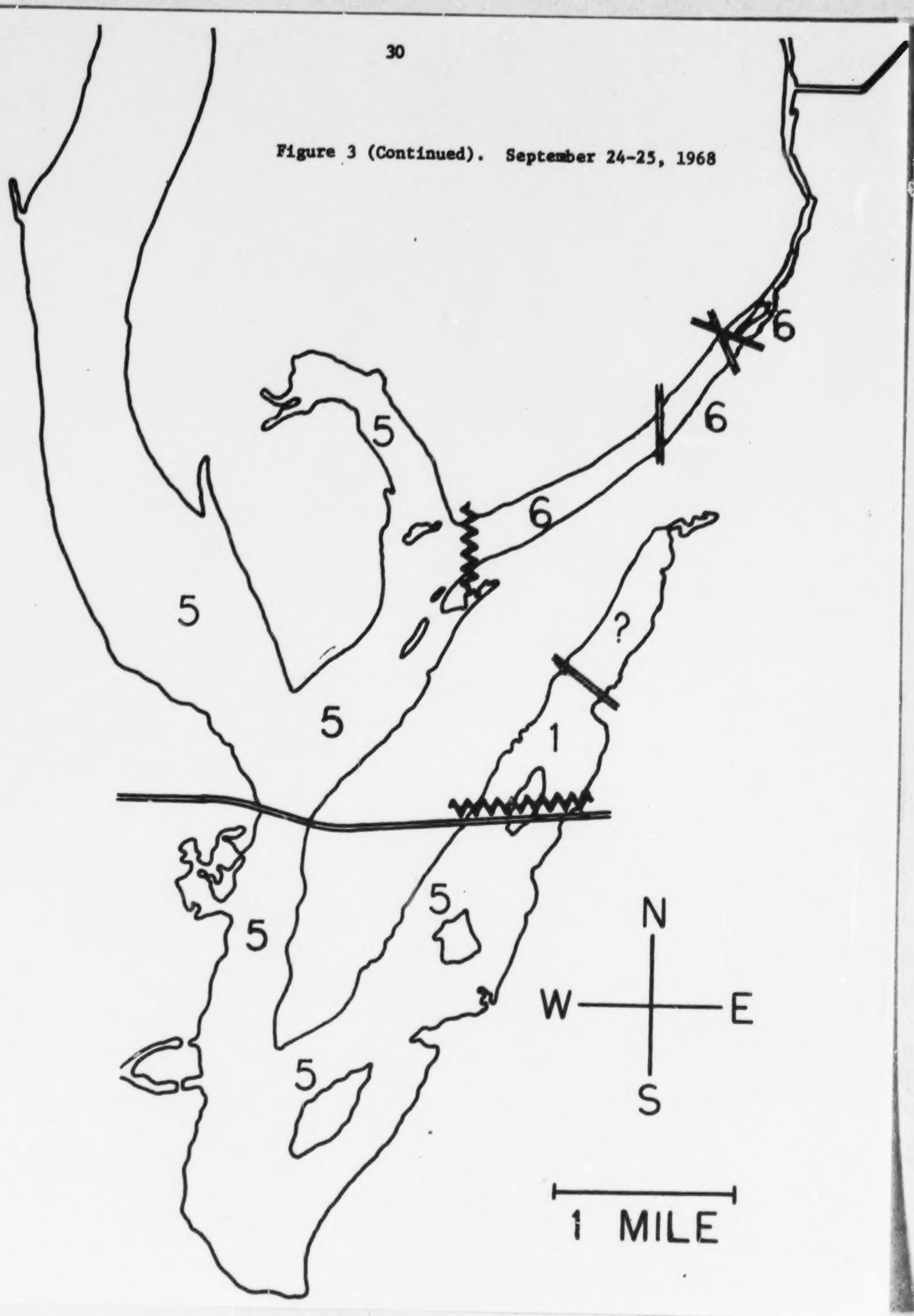

6
6
5
6
5
?
5
1
5
N
5
W
E
S
5
1 MILE

Figure 3 (Continued). October 11-12, 1968

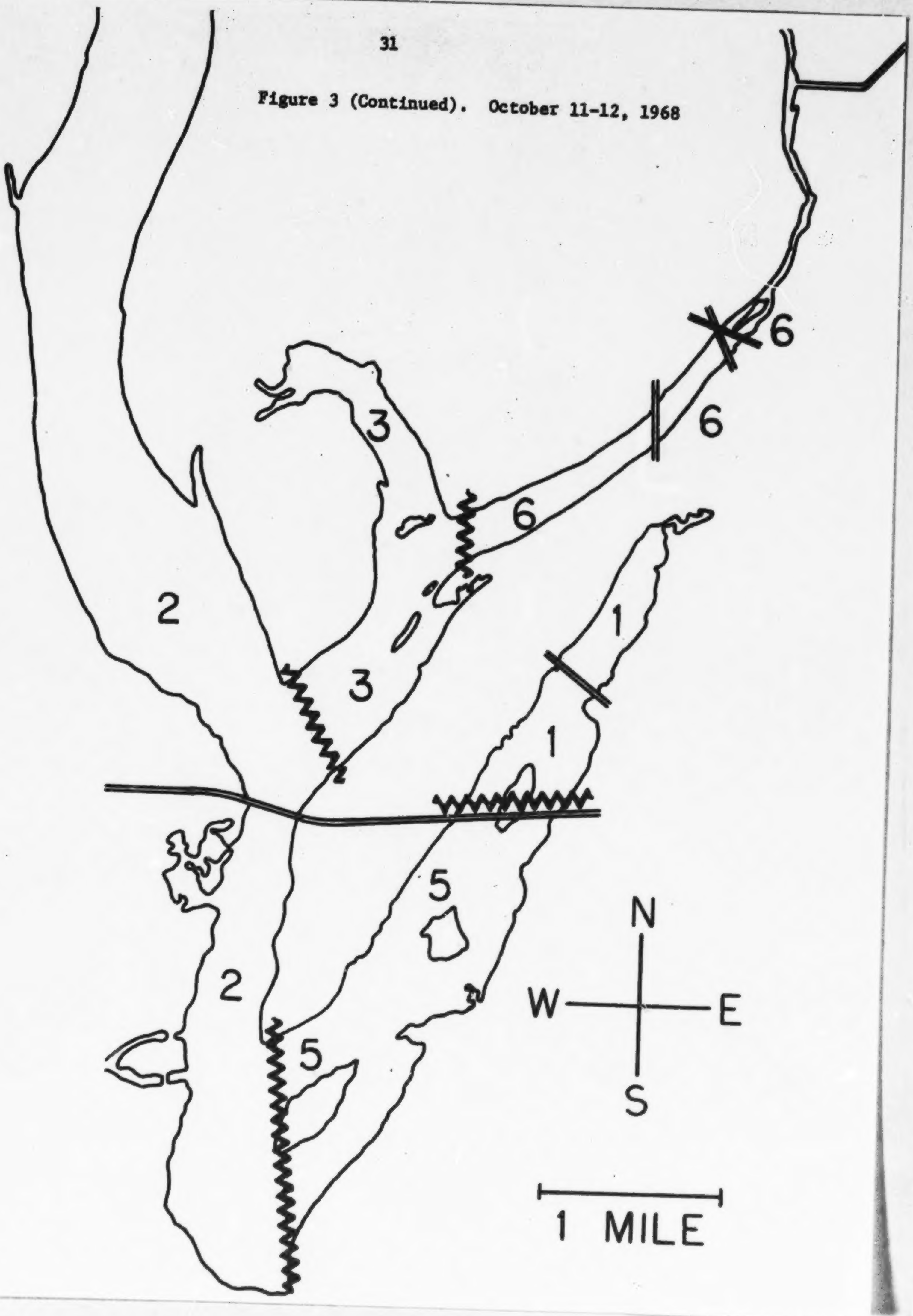

6
6
6
3
1
2
1
3
5
N
W
E
S
2
5
1 MILE

Figure 3 (Continued). October 25-26, 1968

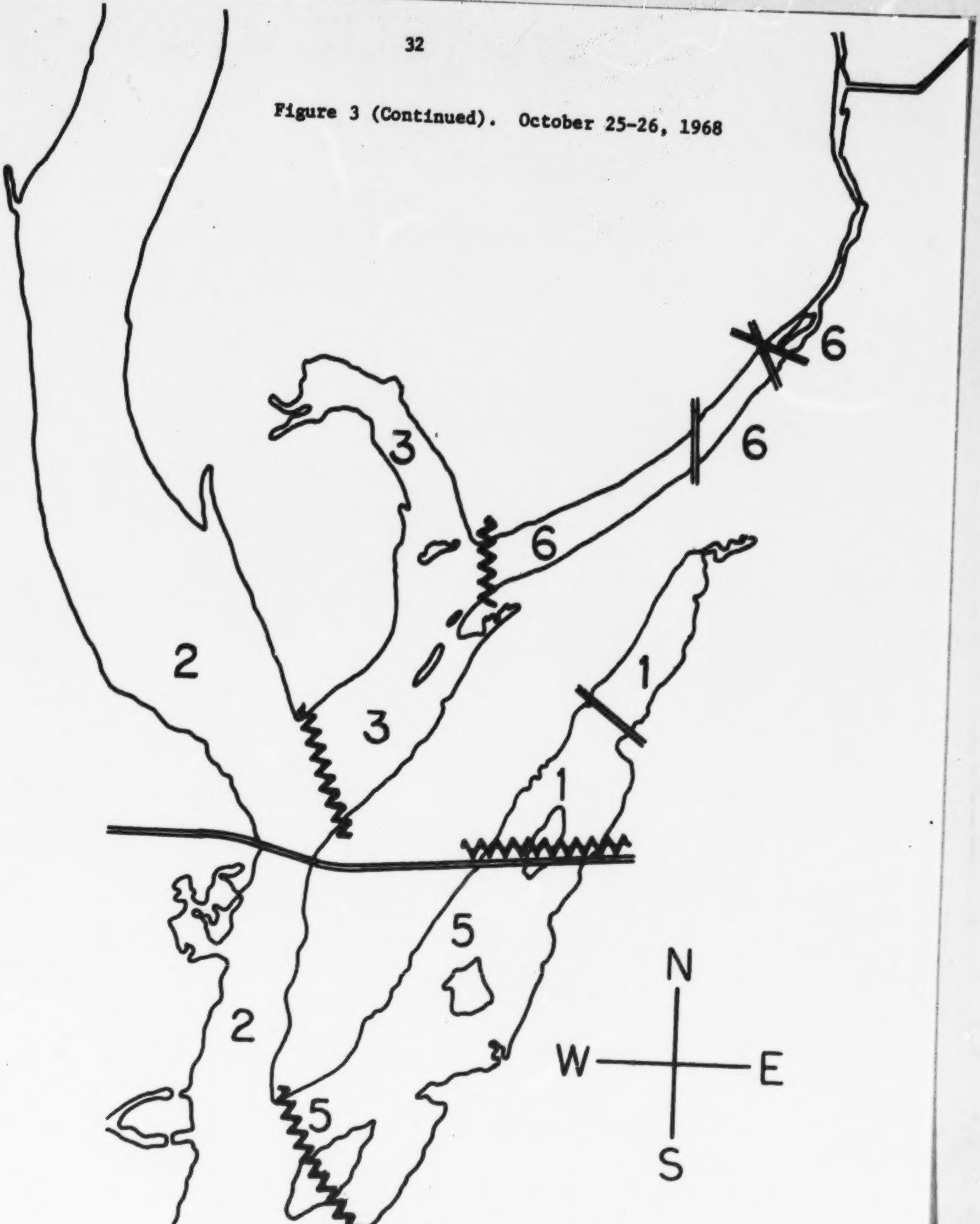

6
6
3
6
1
2
3
1
5
N
W
E
S
2
5
1 MILE

Figure 3 (Continued). November 8-9, 1968

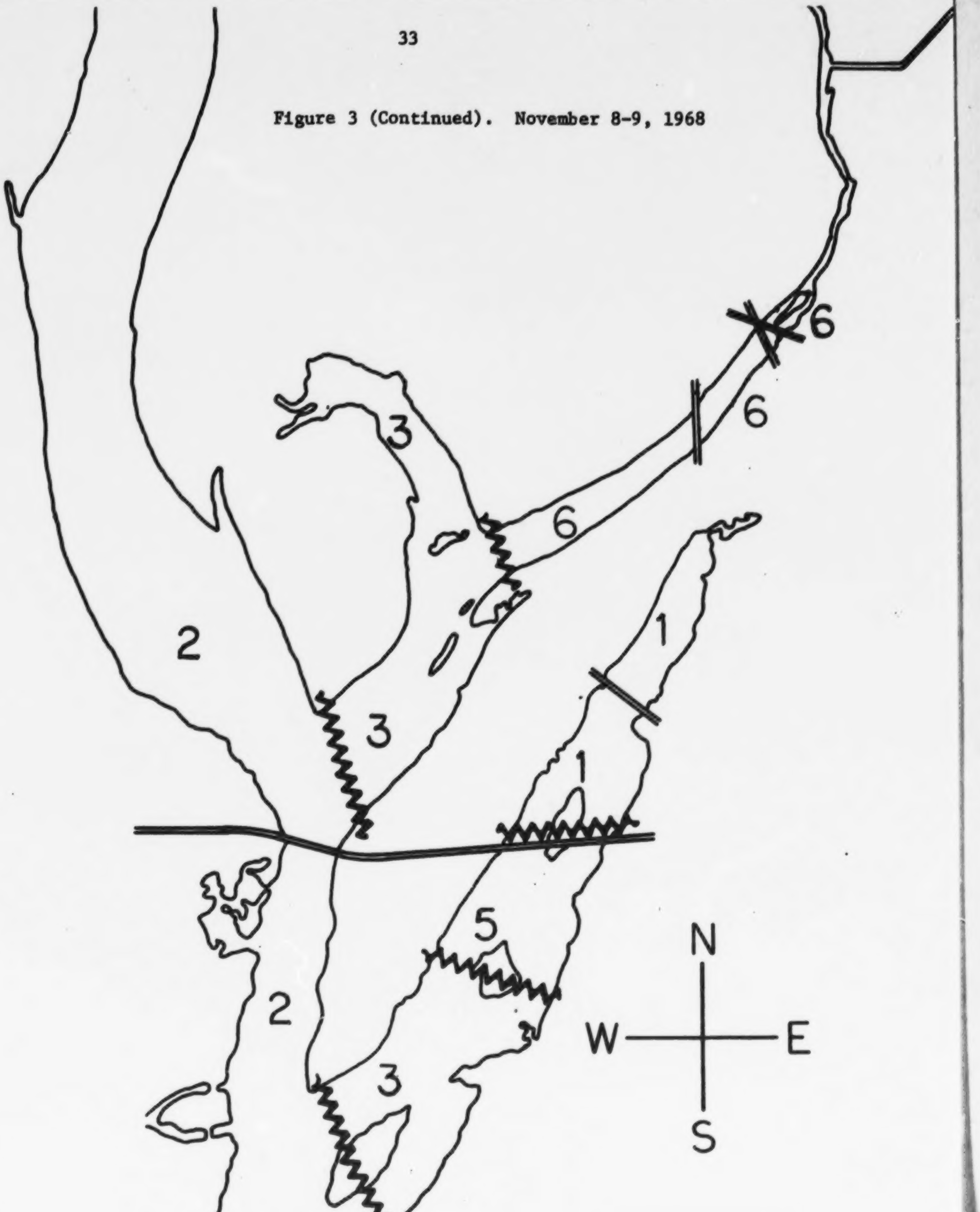

6
6
6
3
1
2
3
1
5
N
W
E
S
2
3
1 MILE

Figure 3 (Continued). November 22-23, 1968

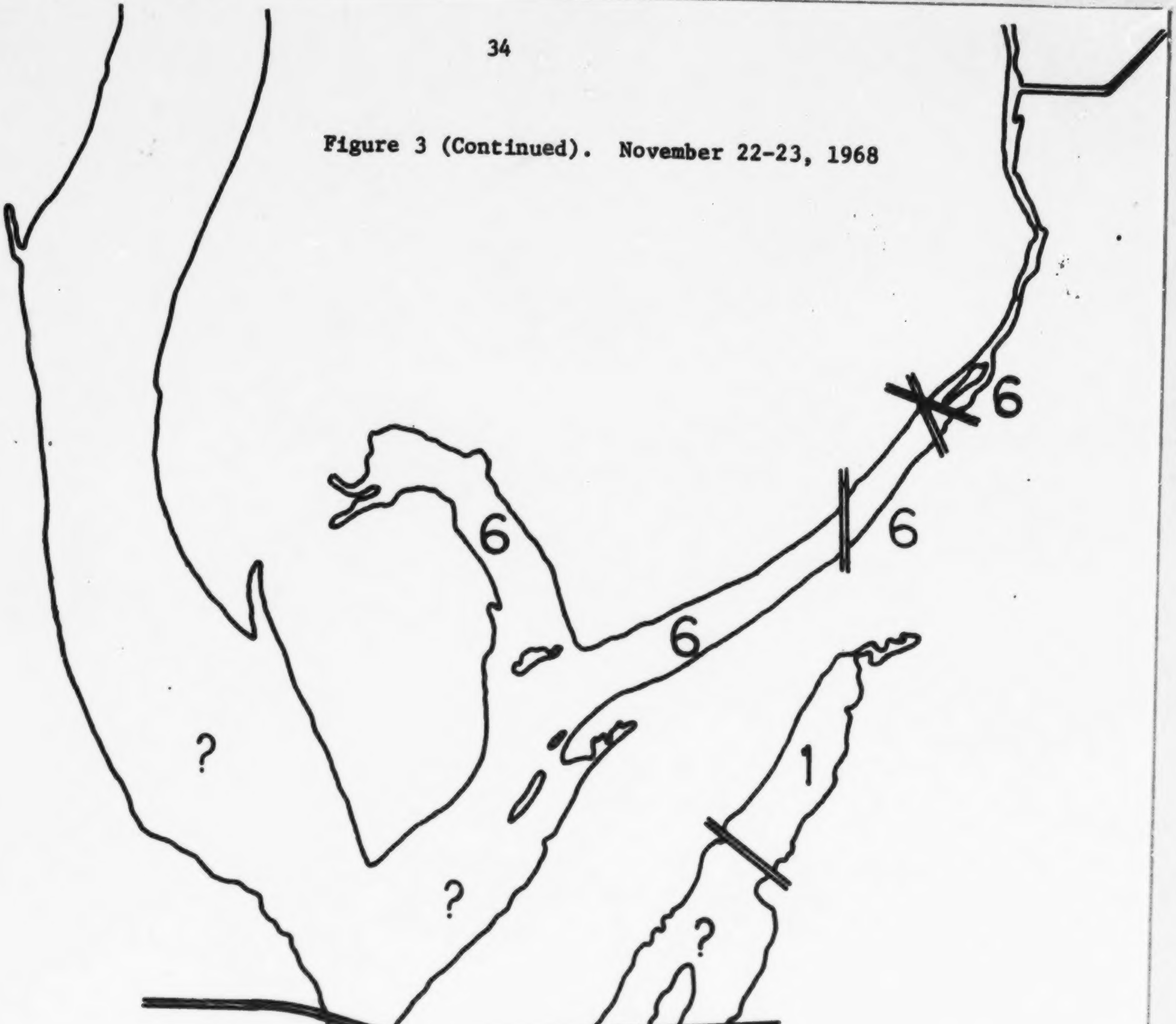

6
6
6
6
1
?
?
?
?
?
?
N
W
E
S
1 MILE

Figure 3 (Continued). December 13-14, 1968

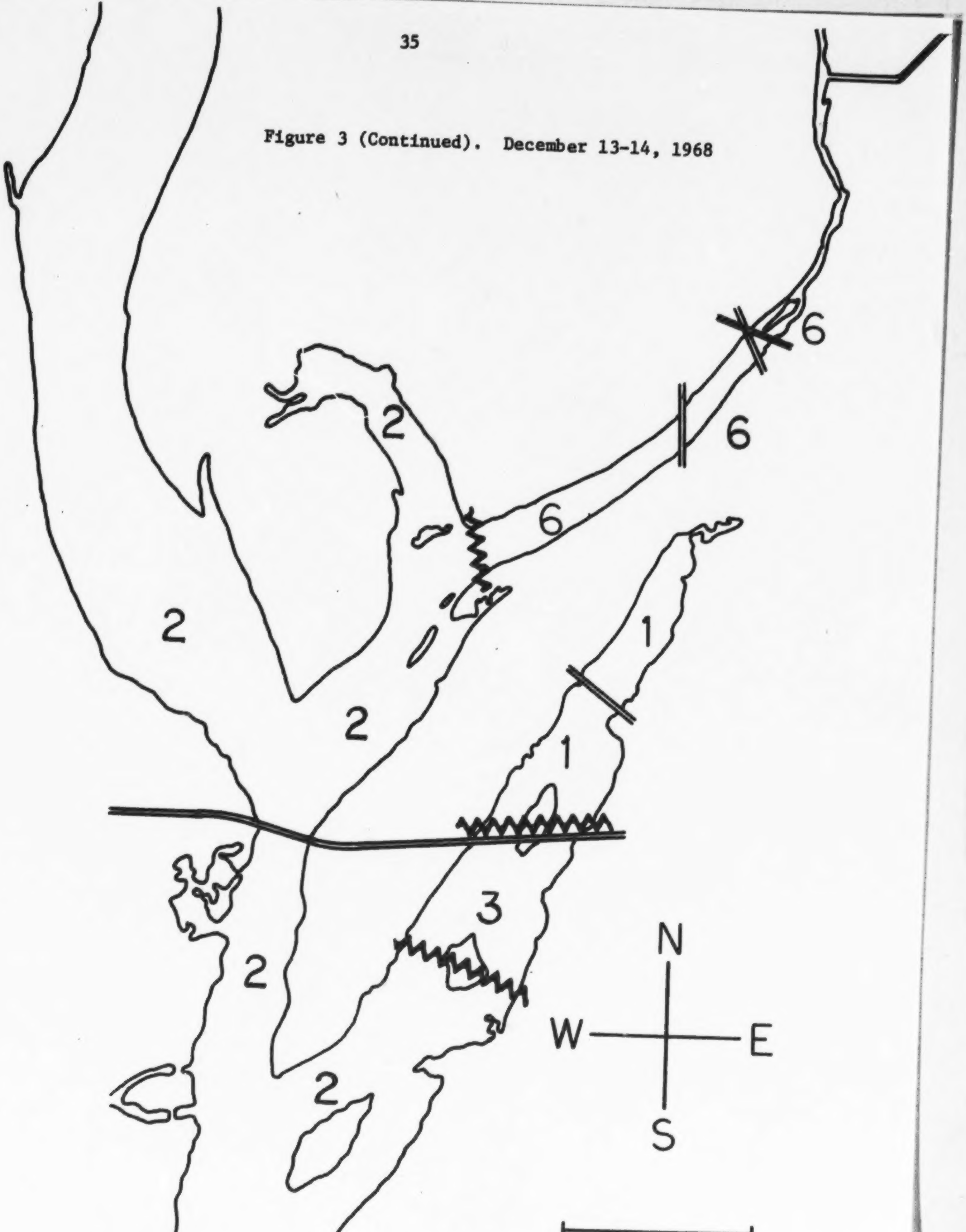

6
6
6
2
2
2
1
1
3
2
2
N
W
E
S
1 MILE

Figure 3 (Continued). March 26-27, 1969

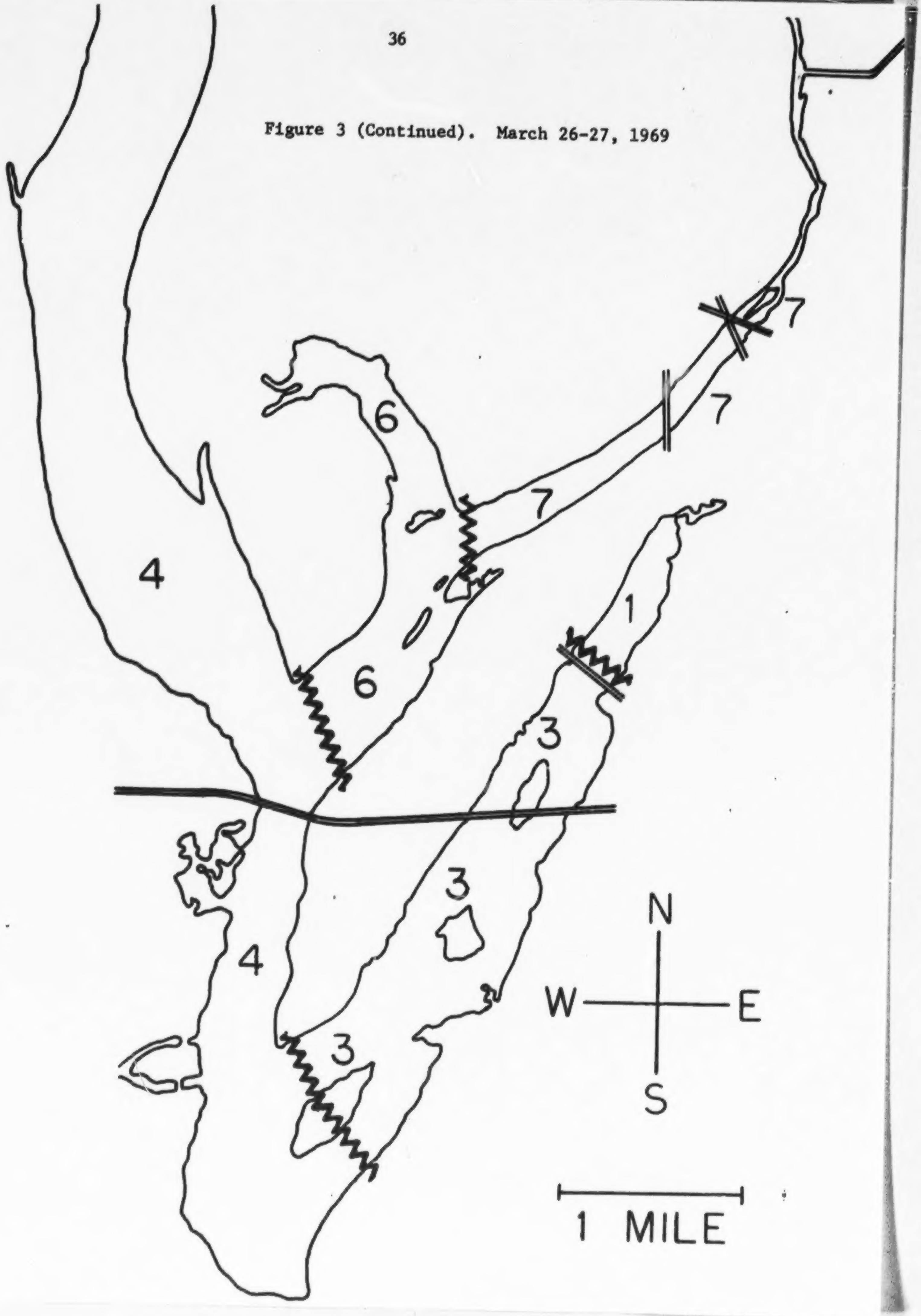

7
7
7
6
4
1
6
3
3
4
3
N
W
E
S
1 MILE

Figure 3 (Continued). April 11, 1969

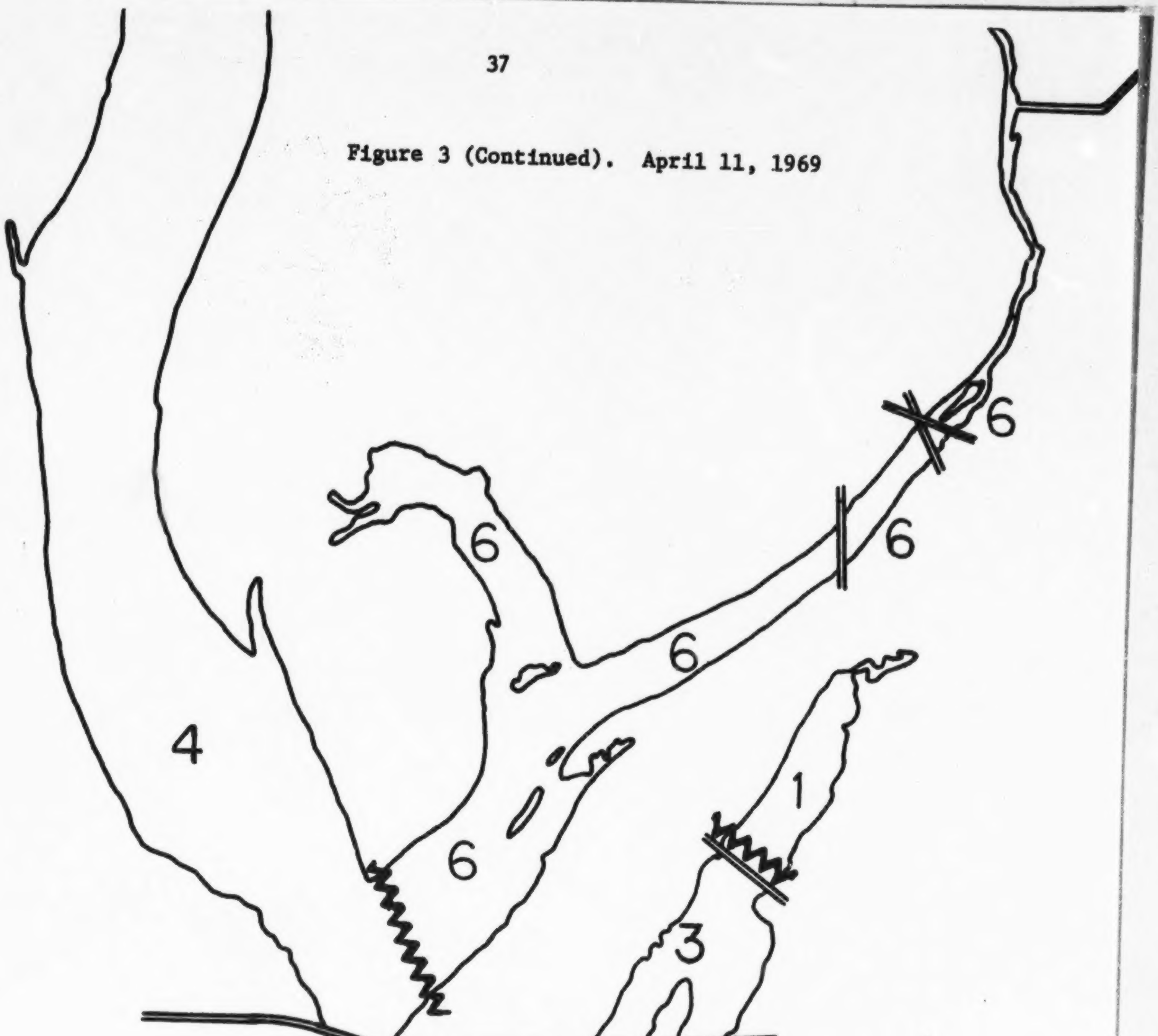

6
6
6
6
6
4
1
6
3
3
4
3
N
W
E
S
1 MILE

Figure 3 (Continued). April 25-26, 1969

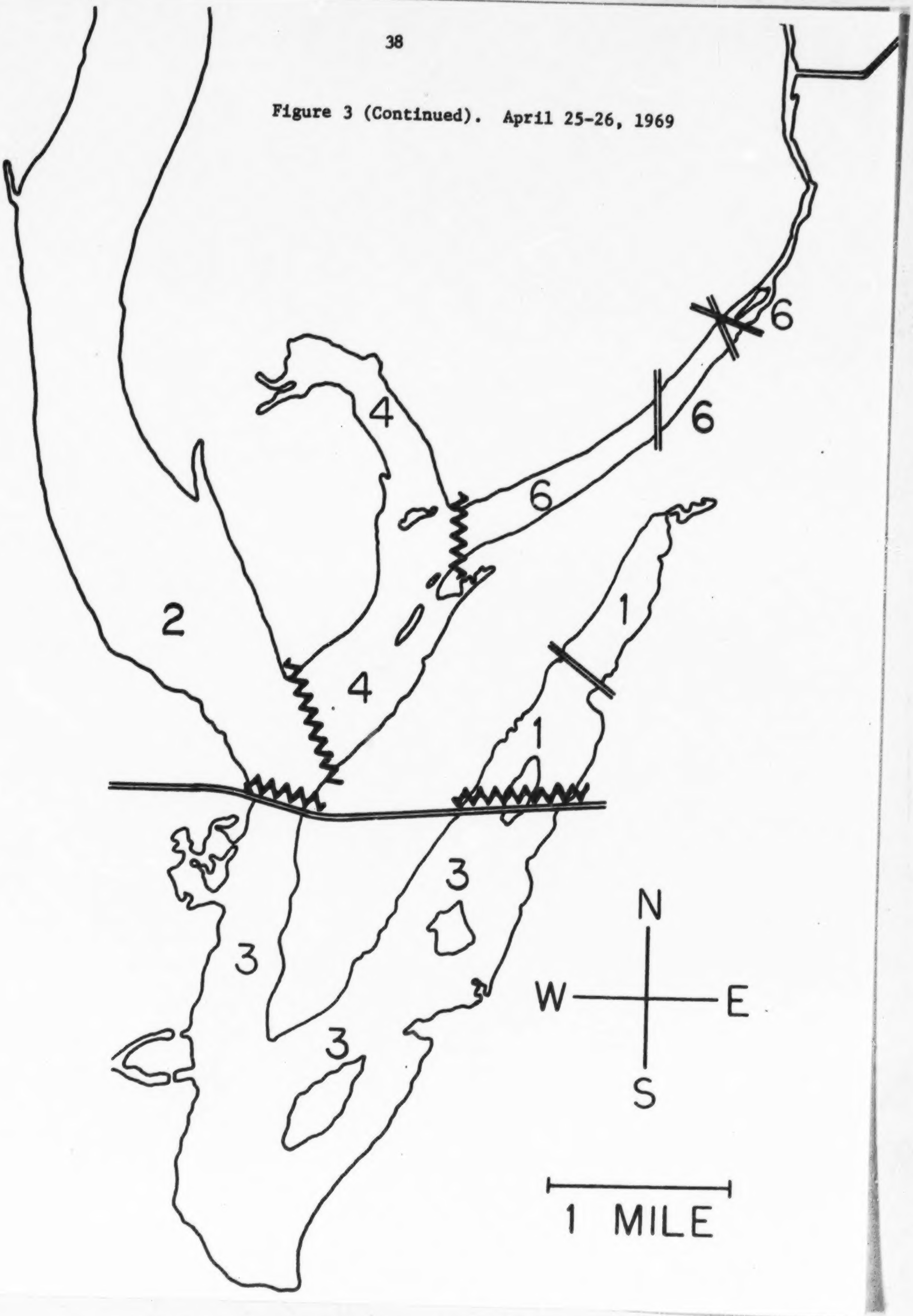

6
6
6
4
4
2
1
1
3
3
3
N
W
E
S
1 MILE

Figure 3 (Continued). May 10, 1969

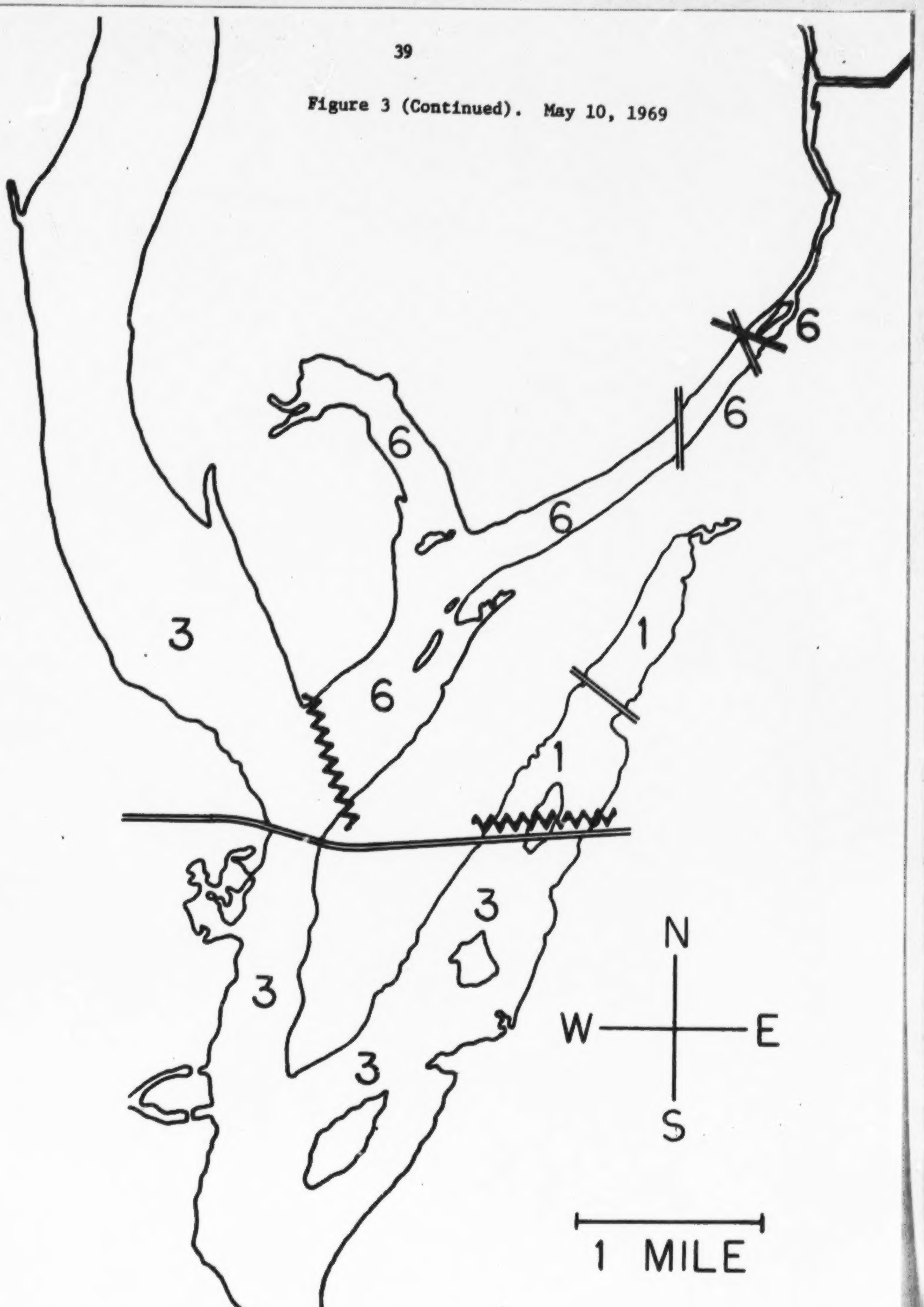
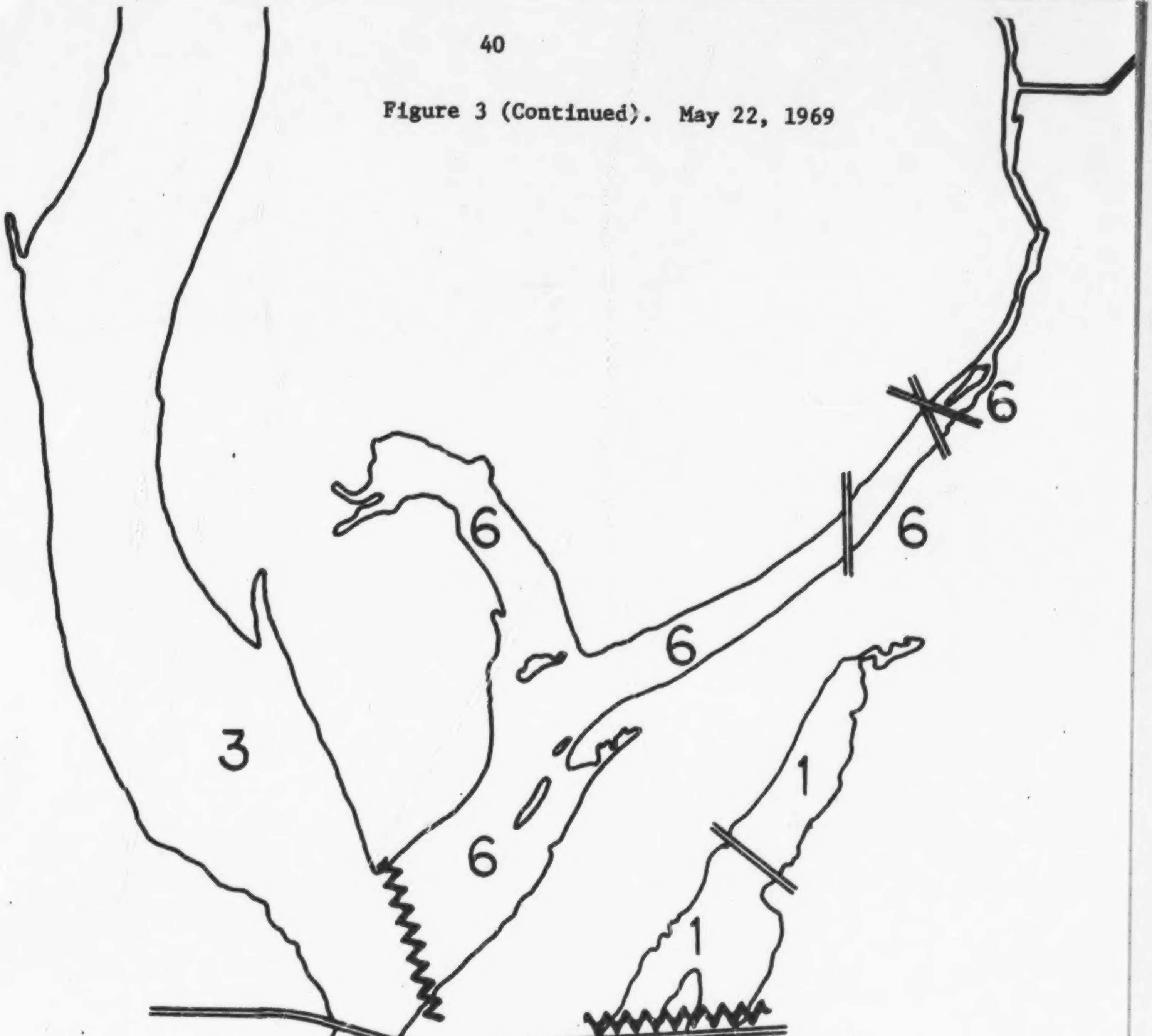

6
6
6
6
3
6
1
1
3
3
3
N
W
E
S
1 MILE

Figure 3 (Continued). May 22, 1969


6
6
6
6
3
1
6
1
3
3
3
N
W
E
S
1 MILE

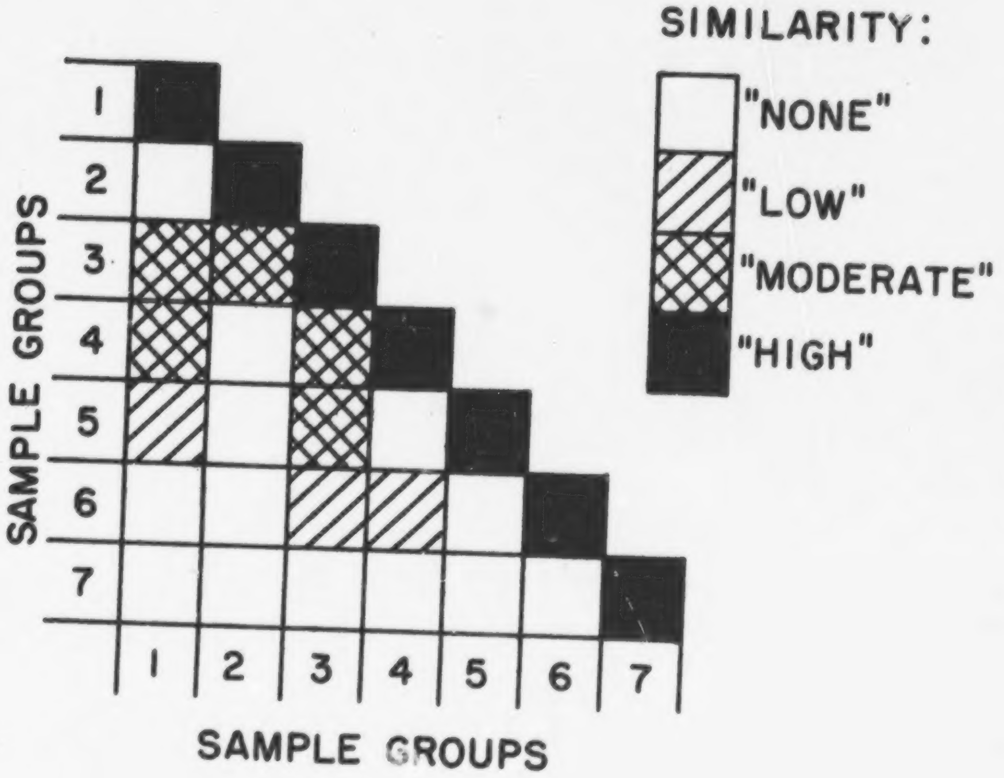


Figure 4. Sample group similarities.

TABLE IV. Listing of the species in eight species groups identified from half the Moses Lake samples collected between July 30, 1968, and May 22, 1969, (every odd-numbered sample when ranked in order of collection).

TAXON	FREQUENCIES IN SAMPLE GROUPS ($\overline{>}$ 5/ml) 1	2	3	4	5	6	7
GROUP 1:							
Crucigenia quadrata	1	0	3	0	6	21	0
Crucigenia tetrapedia	0	1	3	0	5	18	0
Diatoma vulgare	0	0	0	0	0	10	0
Melosira varians	1	0	5	3	4	11	0
Navicula sp. 1	1	0	1	0	0	24	2
Navicula sp. 2	1	0	0	0	1	14	0
GROUP 2:							
Ankistrodesmus falcatus	1	2	1	2	0	32	0
Scenedesmus acuminatus	18	0	7	1	2	35	0
Fragilaria cf. capucina	0	0	1	0	1	26	0
Fragilaria construens	6	1	13	0	20	49	3
Nitzschia acicularis	6	0	10	1	2	38	0
Nitzschia sp. 1	8	1	12	3	1	37	2
GROUP 3:							
Chodatella longiseta	5	0	0	0	0	0	0
Closteriopsis longissima	3	0	0	0	3	0	0
Dimorphococcus sp. 1	10	0	0	0	0	1	0
Cosmarium punctulatum	5	0	0	0	0	0	0
Staurastrum paradoxum	3	0	0	0	2	0	0
Tetraedron caudatum	3	0	0	0	0	0	0
Tetraedron minimum	12	0	0	0	0	0	0
Amphora oralis	3	0	0	0	0	1	0
Cymbella turgida	1	0	0	0	0	0	0
GROUP 4:							
Crucigenia rectangularis	16	0	0	0	4	11	0
Euglena sp. 1	7	0	0	0	2	5	0
Gomphosphaeria locustris	12	0	1	0	3	0	0
Unidentified Colepidae	14	0	0	0	1	0	0

TABLE IV (CONTINUED)

TAXON	1	2	3	4	5	6	7
GROUP 5:							
Mallomonas sp. 1	0	0	2	0	0	3	0
Tintimnopsis cylindrata	0	0	0	0	0	2	0
Peridinium sp. 1	1	0	0	0	1	3	0
GROUP 6:							
Actinastrum gracillimum	6	0	3	1	0	10	0
Coelastrum sphaericum	10	0	2	0	7	10	0
Schroederia ancora	4	0	5	0	23	2	0
Schroederia setigera	7	0	11	0	6	10	0
Asterionella formosa	2	4	18	4	0	10	0
Fragilaria crotonensis	3	4	9	0	5	2	0
Bicoeca sp. 1	0	0	5	1	0	7	0
Mallomonas sp. 2	1	3	16	0	0	6	0
Salpingoeca frequentissima	2	0	4	0	9	2	0
GROUP 7:							
Oocystis lacustris	28	1	12	1	36	10	0
Pediastrum boryanum	28	1	20	4	16	30	0
Pediastrum duplex	17	1	6	2	9	17	0
Scenedesmus quadricauda	28	6	22	5	37	50	0
Sphaerocystis schroeteri	21	2	13	3	41	16	0
Cyclotella meneghiniana	27	8	19	6	15	47	0
Melosira granulata	23	5	25	6	32	38	3
Stephanodiscus niagarae	24	8	23	0	16	4	0
Cryptomonas cf. ovata	23	12	25	6	25	35	0
Cryptomonas sp. 1	7	12	21	4	23	18	0
Anabaena circinalis	13	1	15	1	40	11	0
Aphanizomenon holsaticum	28	11	24	2	48	39	0
Coelosphaerium naeglianum	10	7	15	1	46	2	0
Microcystis aeruginosa	18	1	19	0	47	8	0
GROUP 8:							
Elakatothrix gelatinosa	23	0	5	0	8	2	0
Pediastrum simplex	12	0	0	0	2	0	0
Scenedesmus bijuga	24	0	10	0	4	7	0
Tetraedron muticum	13	0	4	0	0	1	0

TABLE IV (CONTINUED)

TAXON	1	2	3	4	5	6	7
GROUP 8 (CONTINUED):							
Synedra arcuata	15	0	2	0	0	4	0
Bicoeca lacustris	6	1	13	0	12	2	0
Cryptomonas cf. obovoidea	2	0	0	0	0	4	0
Codonella cratera	9	0	5	2	1	7	0
Unidentified Oligotrichida	15	0	5	0	15	1	0

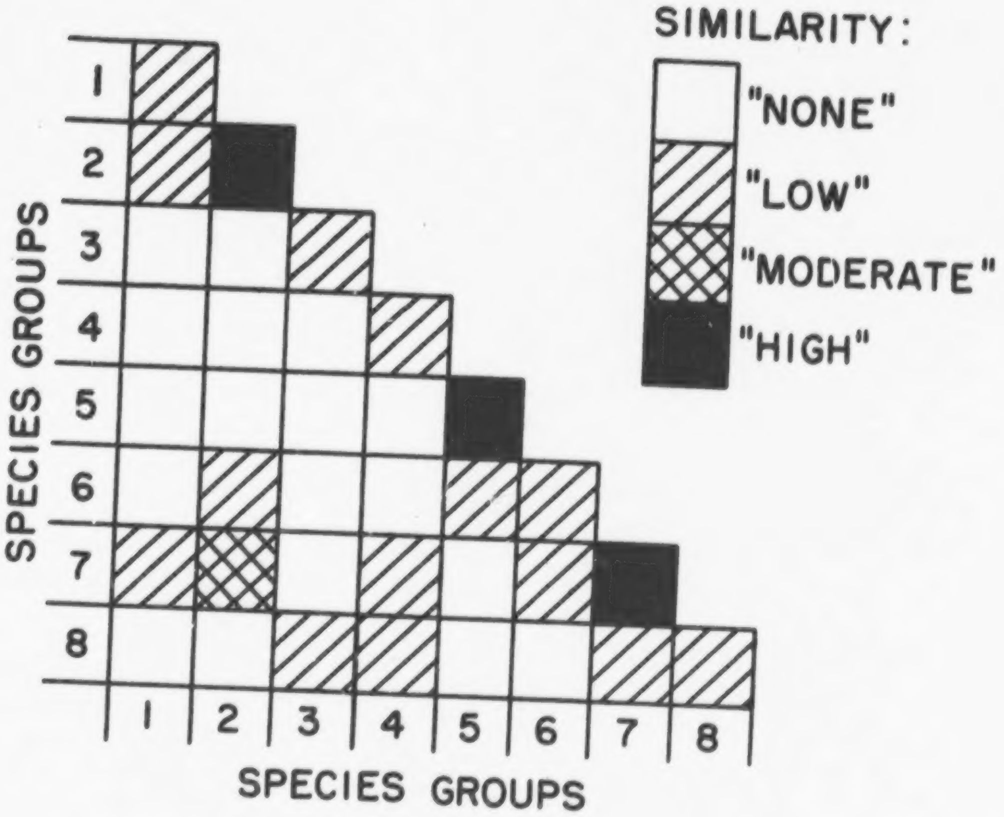
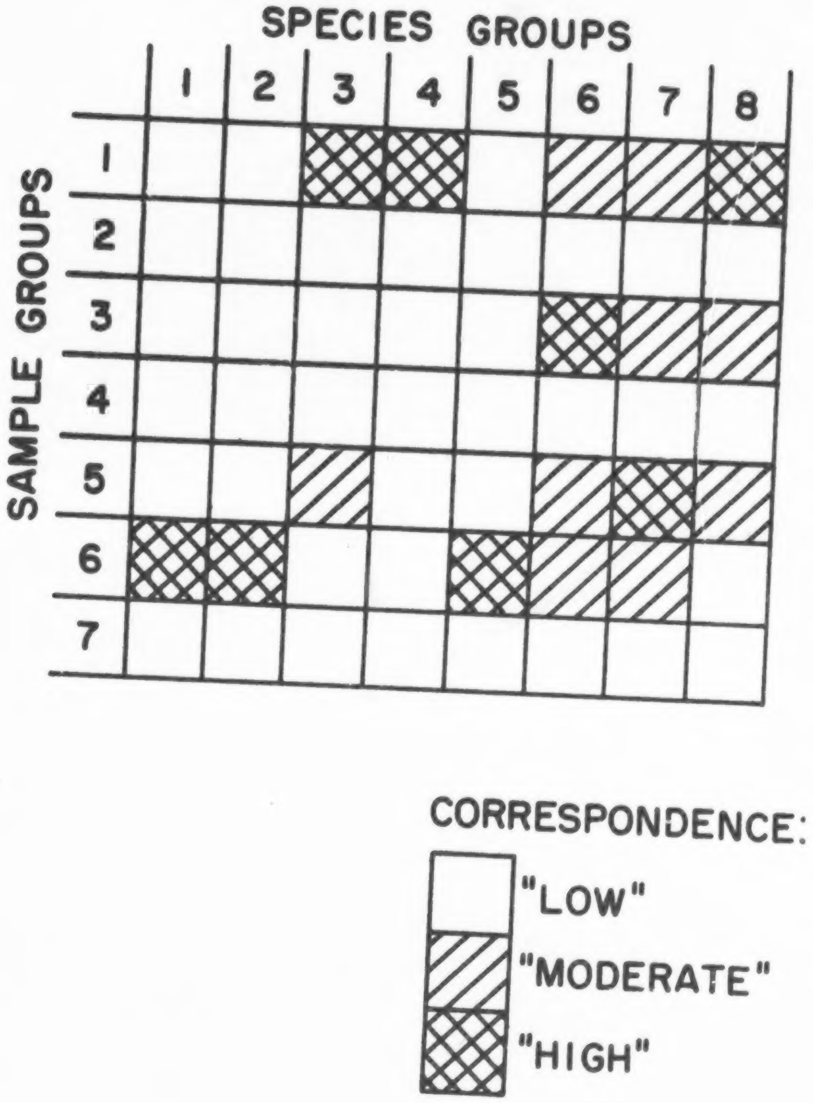

SIMILARITY:
"NONE"
"LOW"
"MODERATE"
"HIGH"
SPECIES GROUPS
1
2
3
4
5
6
7
8
SPECIES GROUPS

Figure 5. Species group similarities.



	SPECIES GROUPS							
SAMPLE GROUPS	1	2	3	4	5	6	7	8
1			▦	▦		▨	▨	▦
2								
3						▦	▨	▨
4								
5			▨			▨	▦	▨
6	▦	▦			▦	▨	▨	
7								

CORRESPONDENCE:
□ "LOW"
▨ "MODERATE"
▦ "HIGH"

Figure 6. Correspondence between species groups and sample groups.

TABLE V

Sample Group Mean Values (Physico-Chemical Data)

	1	2	3	4	5	6	7
TEMP (C)	12.41	17.30	14.07	10.20	13.72	13.73	10.83
COND (mmHOS/cm)	539.8	423.5	462.0	392.5	489.4	462.1	258.0
SECCHI (M)	0.59	1.19	0.75	0.22	1.04	0.50	0.06
ALPHA (/M)	14.01	5.92	7.61	34.37	4.10	23.46	124.29
PO4P (mg/l)	0.83	0.13	0.18	0.34	0.14	0.18	0.75
TOTAL P (mg/l)	1.44	0.32	0.58	0.74	0.45	0.49	1.54
NO3N (mg/l)	0.46	0.67	0.58	---	0.34	1.46	---
NH4N (mg/l)	---	---	---	---	---	---	---
N/P (atoms)	10.12	26.23	27.45	---	18.70	49.99	---
TOT.SES. (mg/l)	26.97	8.54	20.88	63.06	24.53	34.77	303.10
COM.SES. (mg/l)	20.06	4.42	13.23	22.51	18.74	12.32	71.98
% C.SES.	78.29	56.66	63.33	37.18	68.93	40.14	23.83
CARBON (mg/l)	5.65	1.14	3.65	4.47	2.68	3.14	15.15
CHLORA (µg/l)	98.06	12.33	94.07	40.36	179.78	30.70	23.53
ACID F. (Ro/Ra)	2.13	2.08	2.20	2.17	2.15	1.96	1.86
TOT.SES./α	2.06	1.39	3.17	1.93	2.29	1.87	2.42
COM.SES./α	1.45	0.84	2.13	0.77	1.28	0.74	0.57
CARBON/α	0.44	0.28	0.58	0.15	0.34	0.18	0.12

TABLE VI

Sample Group Coefficients of Variation ($\frac{\sigma}{\bar{x}}$ x 100)

Parentheses enclose the no. of samples upon which the statistics were determined.

	1	2	3	4	5	6	7
TEMP	56.64(17)	197.80(12)	43.49(22)	34.50(4)	21.52(11)	43.77(38)	2.85(3)
COND	12.92(17)	12.74(12)	12.15(25)	9.96(6)	2.81(5)	22.22(36)	1.14(3)
SECCHI	51.24(14)	50.47(12)	62.42(24)	52.47(6)	19.34(5)	53.27(35)	0.01(3)
ALPHA	52.99(13)	103.32(8)	51.86(21)	42.84(6)	0.00(1)	96.74(30)	34.03(3)
PO4P	84.92(17)	80.26(12)	151.96(25)	34.12(6)	88.10(5)	94.68(36)	7.58(3)
TOTAL P	46.26(17)	20.28(10)	86.06(23)	27.52(6)	15.35(10)	61.98(35)	10.55(3)
NO3N	88.32(9)	42.25(9)	24.73(6)	---(0)	62.15(10)	18.41(15)	---(0)
NH4N	---(0)	---(0)	---(0)	---(0)	---(0)	---(0)	---(0)
N/P	228.17(8)	71.38(9)	55.36(6)	---(0)	57.04(3)	66.24(13)	---(0)
TOTSES	42.64(22)	66.86(12)	57.81(25)	55.07(6)	74.95(24)	99.20(43)	10.92(3)
COMSES	33.42(22)	46.49(12)	62.34(25)	49.03(6)	96.68(24)	86.27(42)	9.93(3)
% C.SES.	15.88(22)	19.82(12)	18.18(25)	24.05(6)	30.04(24)	40.24(42)	7.63(3)
CARBON	36.37(17)	23.31(10)	75.79(23)	47.30(6)	44.33(10)	72.02(35)	13.23(3)
CHLORA	90.60(18)	47.76(12)	108.54(25)	33.74(5)	112.25(12)	113.64(37)	30.76(3)
ACID F.	6.86(18)	4.72(12)	12.41(25)	9.24(5)	7.27(12)	11.70(37)	4.46(3)
TOTSES/α	56.20(13)	25.66(8)	64.79(21)	44.75(6)	0.00(1)	40.07(30)	35.24(3)
COMSES/α	38.71(13)	37.41(8)	73.74(21)	67.86(6)	0.00(1)	40.16(29)	31.17(3)
CARBON/α	35.75(13)	38.53(8)	69.07(21)	59.57(6)	0.00(1)	37.27(30)	27.10(3)

TABLE VII

Number of Representatives of Toxonomic Classes in Each Sample Group.

Representatives in Sample Groups (#Detected/#>5 per ml)

Taxonomic Class	1	2	3	4	5	6	7	Total
Chlorophyceae	37/30	12/7	22/17	10/8	25/19	31/22	0/0	47
Euglenophyceae	1/1	0/0	1/0	0/0	1/1	1/1	0/0	1
Bacillariophyceae	22/18	14/8	19/13	14/6	18/11	26/21	7/5	29
Chrysophyceae	7/5	4/2	6/6	3/1	5/2	9/5	0/0	12
Xanthophyceae	0/0	0/0	0/0	0/0	0/0	1/0	0/0	1
Dinophyceae	2/2	0/0	2/0	0/0	2/2	2/1	0/0	2
Cryptophyceae	3/3	2/2	2/2	2/2	2/2	3/3	0/0	3
Cyanophyceae	7/7	5/5	7/7	3/3	7/7	6/6	0/0	7
Ciliatea	6/6	3/0	5/2	4/1	4/4	6/4	1/1	7
Sarcodina	0/0	0/0	0/0	0/0	1/0	0/0	0/0	1
Miscellaneous	1/1	0/0	1/1	0/0	0/0	1/1	0/0	1
TOTAL	86/72	40/24	65/49	37/21	65/49	87/64	8/6	111
Chlorophyceae/ Bacilloriophyceae Ratio	1.68:1/ 1.67:1	0.86:1/ 0.87:1	1.16:1/ 1.31:1	0.71:1/ 1.33:1	1.39:1/ 1.73:1	1.19:1/ 1.05:1	-/-	

TABLE VIII

Summary of the temporo-spatial distribution of sample group members (biotic community types) in Moses Lake between July 30, 1968 and May 22, 1969.

	A	B	C	D	E	F	G	H	I	J	K
July 30 - Aug. 1/68	6	■	5	5	5	■	■	■	■	■	■
Aug. 8-9/68	6	6	5	5	5	5	5	5	5	1	1
Aug. 16-17/68	6	6	5	5	5	5	5	5	5	1	1
Aug. 23-24/68	6	6	5	5	5	5	5	5	5	1	1
Aug. 30-31/68	6	6	5	5	5	5	5	5	5	1	1
Sept. 17-18/68	6	6	6	5	5	5	5	5	5	1	1
Sept. 24-25/68	6	6	6	5	5	5	5	5	5	1	■
Oct. 11-12/68	6	6	6	3	3	2	2	5	5	1	1
Oct. 25-26/68	6	6	6	3	3	2	2	5	5	1	1
Nov. 8-9/68	6	6	6	3	3	2	2	3	5	1	1
Nov. 22-23/68	6	6	6	6	■	■	■	■	■	■	1
Dec. 13-14/68	6	6	6	2	2	2	2	2	3	1	1
Mar. 26-27/69	7	7	7	6	6	4	4	3	3	3	1
April 11/69	6	6	6	6	6	4	4	3	3	3	1
April 25-26/69	6	6	6	4	4	2	3	3	3	1	1
May 10/69	6	6	6	6	6	3	3	3	3	1	1
May 22/69	6	6	6	6	6	3	3	3	3	1	1

highest of all groups also for 1) Orthophosphate
2) Total phosphate
3) Percent combustible seston
4) Particulate carbon

: - Consistantly high in plankton biomass, as shown by particulate carbon (highest mean), percent combustible seston (highest mean, lowest variability), and chlorophyll a (second highest mean) measurements. This is the group's most prominent characteristic.

: - As shown in Figure 4, this group has moderate biological similarity with groups 3, and 4, and low similarity with group 5.

: - Plankton taxonomy (Table VII): 86 taxa detected, 72 (83%) attained 5 cells/ml. Mainly chlorophyceae; the ratio of chlorophyceae: bacillariophyceae was higher than any other group (1.68:1 for detected taxa, 1.67:1 for taxa attaining 5 cells/ml), whereas, most other sample groups had ratios near 1:1). There were also more species of ciliated protozoa in this group of samples than in the other groups. No xanthophyceae or sarcodina were detected.

: - In general (except for nitrate), this region of Moses Lake was richest in nutrients and organisms, probably owing to the sewage treatment plant discharge.

Sample Group 2

: - 12 samples from D, E, F, G, H in October-December.

: - The least variable group in more respects than any other group. Most uniform with respect to 1) Secchi disc depth
2) Particulate carbon
3) Acid factor
4) Total seston/alpha ratio

: - Highest mean temperature but also greatest temperature variability among the groups. Highest Secchi disc depth mean of all groups (and least variable).

: - This group had the lowest mean values of all groups for:

1) Alpha
2) Orthophosphate
3) Total phosphate
4) Total seston
5) Combustible seston
6) Particulate carbon
7) Chlorophyll a
8) Total seston/alpha ratio

: - The high mean with low variability for Secchi disc depth and low means with low variability for 1) Particulate carbon
2) Chlorophyll a
3) Total seston/alpha

seem particularly significant, and probably characterize this group best. They probably indicate consistantly low plankton biomass and high water clarity.

: - Moderate biological similarity to group 3 (Figure 4).

: - Plankton taxonomy (Table VII): 40 taxa detected, 24 (60%) attained 5 cells/ml. Ratio of chlorophyceae: bacillariophyceae 0.86:1 for detected taxa, 0.87:1 for taxa attaining 5 cells/ml. No euglenophyceae, xanthophyceae, dinophyceae, or sarcodina were detected. No ciliatea attained 5 cells/ml.

: - This sample group represents the main body of the lake during the late autumn and winter.

Sample Group 3

: - 25 samples from D, E in October-November and F, G, H, I, J in March-May.

: - The most highly variable of all sample groups, being the most variable group with respect to
1) Secchi disc depth
2) Total phosphate
3) Particulate carbon
4) Acid factor
5) Total seston/alpha ratio
6) Combustible seston/alpha ratio
7) Particulate carbon/alpha ratio

: - The least variable group in only one respect: Nitrogen/phosphorous ratio.

: - In spite of the great variability, the mean values were highest of all groups for
1) Acid factor
2) Total seston/alpha ratio
3) Combustible seston/alpha ratio
4) Particulate carbon/alpha ratio

: - This group tended to have moderately high amounts of plankton, which was in variable physiological state but generally healthy (judging from acid factor). Also, this group characteristically had fairly low amounts (lowest of all groups) of suspended inorganic particles.

: - Moderate biological similarity to groups 1, 2, 4, and 5, low similarity to group 6 (Figure 4).

: - Plankton taxonomy (Table VII): 65 taxa detected, 49 (75%) attained 5 cells/ml.

Chlorophyceae: bacillariophyceae ratio 1.16:1 for detected taxa and 1.31:1 for taxa attaining 5/ml. No euglenophyceae attained 5 cells/ml. No xanthophyceae, dinophyceae, or sarcodina were detected.

Sample Group 4

: - 6 samples from D, E, F, G in March-April.

: - Low calculated variability, perhaps due to the few samples in the group. Least variable group with respect to

1) Conductivity
2) Orthophosphate
3) Total phosphate
4) Alpha
5) (Second least variable for chlorophyll *a*).

: - Lowest mean values of all groups for

1) Temperature
2) Conductivity
3) Percent Combustible seston
4) Secchi disc depth
5) Particulate carbon/alpha ratio

: - Highest mean values of all groups for

1) Alpha
2) Total seston
3) Combustible seston

: - This group is characterized by high turbidity, moderately high orthophosphate and total phosphate concentrations, fairly low chlorophyll a concentrations and high total seston and combustible seston concentrations. These characteristics probably reflect the large amount of runoff-borne terrigenous suspended matter and nutrients, and low plankton populations that are to be expected in early spring.

: - Moderate biological similarity to groups 1 and 3 and low similarity to group 6 (Figure 4). Since at this time of year, the influence of Crab Creek upon the lake is extensive and obvious, a strong biological similarity between this group and group 6 might be expected. However, the fact that they are only weakly similar suggests that the algae imported from the creek are not what most strongly modify the biota in the adjacent parts of the lake, but rather, the water causes somewhat similar species to grow when conditions are favorable (as happened when fall advanced and when the summer flora had not yet grown up in the following spring). This, however, is not proven.

: - Plankton taxonomy (Table VII): 37 taxa detected, 21 (57%) attained 5 cells/ml. Chlorophyceae: bacillariophyceae ratio 0.71:1 for detected taxa, 1.33:1 for taxa attaining 5/ml (indicating the presence of several diatoms at concentrations less than 5 cells/ml). No euglenophyceae, xanthophyceae, dinophyceae, or sarcodina.

Sample Group 5

: - 31 samples from C, D, E, F, G, H, I in August-October.

: - Only one third of the samples were accompanied by chemical measurements, so that physio-chemical features of this group are not as well known as would be desirable.

: - Least variable group in only one respect: Temperature.

: - Rivals group 4 in uniformity of conductivity but not in mean value.

: - Lowest group in only one respect: Nitrate nitrogen.

: - Rivals group 2 in low value for mean orthophosphate.

: - Quite variable in most measured parameters.

: - In general, this group could be characterized by high temperatures, conductivity, Secchi disc depth, combustible seston, percent combustible seston, chlorophyll a, acid factor, total seston/alpha ratio, combustible seston/alpha ratio, and particulate carbon/alpha ratio, and by low turbidity, nutrient concentrations, N/P ratio, and total seston.

: - The mean particulate carbon was about mid-range.

: - The water belonging to this group was moderately clear, the particulate matter present originating within the lake (being in high proportion living and healthy plankton).

: - Moderate biological similarity with group 3 and low similarity with group 1 (Figure 4).

: - Plankton taxonomy (Table VII): 65 taxa detected, 49 (75%) attained 5 cells/ml. Chlorophyceae: bacilleriophyceae ratio 1.39:1 for detected taxa and 1.73:1 for taxa attaining 5/ml (indicating that the fraction of diatoms which were never 5 cells/ml was disproportionately larger than expected from the total number of species). Conditions seem to favor green algae more than diatoms. No xanthophyceae were detected. No sarcodina attained 5/ml.

Sample Group 6

: - 45 samples from A, B in August-May, C in September-May, D in November-May, and E in March-May.

: - The largest of all sample groups.

: - The least variable in one respect only: Nitrate nitrogen.

: - Most variable of all groups with respect to

1) Conductivity
2) Orthophosphate
3) Total seston
4) Percent combustible seston
5) Chlorophyll a.

: - Lowest group mean for

1) Acid factor
2) Combustible seston/alpha ratio

: - Highest group mean for

1) Nitrate nitrogen
2) N/P ratio

: - This group was almost always associated with visible influence by Crab Creek inflow upon the lake. Associated phenomena with this fact were high variability in the nature of suspended matter, the least healthy condition of chlorophyll-bearing plankton populations (highest proportion of "dead" chlorophyll), relatively fairly low orthophosphate concentrations, very high nitrate concentrations, and a high proportion of inorganic suspended matter.

: - Low biological similarity with groups 3 and 4; no similarity to any others (Figure 4).

: - Plankton taxonomy (Table VII): 87 taxa detected, 64 (74%) attained 5/ml. Chlorophyceae: bacillariophyceae ratio 1.19:1 for detected taxa and 1.05:1 for taxa attaining 5/ml (indicating a higher fraction of green algae than diatoms were less abundant than 5/ml). Conditions seem to favor diatoms as a group rather than green algae. No xanthophyceae attained 5/ml. No sarcodina were detected.

Sample Group 7

: - 3 samples from A, B, C in March.

: - Statistically very "uniform" owing to the fact that these 3 samples came from adjacent sites during peak runoff, and would be expected to be highly similar.

: - Very low mean values for

1) Conductivity
2) Secchi disc depth
3) Percent combustible seston
4) Acid factor
5) Combustible seston/alpha ratio
6) Particulate carbon/alpha ratio

: - Very high mean value for

1) Alpha
2) Total seston
3) Particulate carbon

: - Most measured factors reflect the extremely high turbidity of the runoff water, which contained large quantities of particulate inorganic and organic matter, low concentrations of dissolved solids (low conductivity), high orthophosphate and total phosphate concentrations, and small quantities of living plankton (low chlorophyll a and very low acid factor).

: - This group has no biological similarity to any other group (Figure 4).

: - Plankton taxonomy (Table VII): 8 taxa detected, 6 (75%) attained 5 cells/ml. No chlorophyceae were detected; only 7 bacillariophyceae and 1 ciliatea. The one ciliatea attained 5/ml.

Plankton Crops and Associated Factors - Seasonal Variation

In addition to describing the community structure as background for future flushing experiments, information on the quantity of algae and its seasonal distribution was also necessary. As with data on sample groups, considerable difference in algal quantity, indicated by chlorophyll a, was noted throughout the lake (Figure 7). Chlorophyll a content in Parker Horn and the main lake (Stations A - G) was considerably less than that in Pelican Horn (Stations H - K) in both the fall of 1968 and in the spring of 1969. This difference is made clearer if mean values for those stations in Parker and Pelican Horns are compared (Figure 8). The difference is most striking in the spring of 1969, when not only was the quantity of chlorophyll a more than four times greater in Pelican than Parker Horn, but the peak occurred earlier - both indicating the apparent better growing conditions in Pelican than Parker Horn.

Turbid water in Parker Horn and the lower lake was observed in the spring of 1969 as a result of high flows from Crab Creek, but this turbidity did not extend into Pelican Horn. Thus, light limitation in the relatively turbid areas was considered a possible factor explaining the differences in

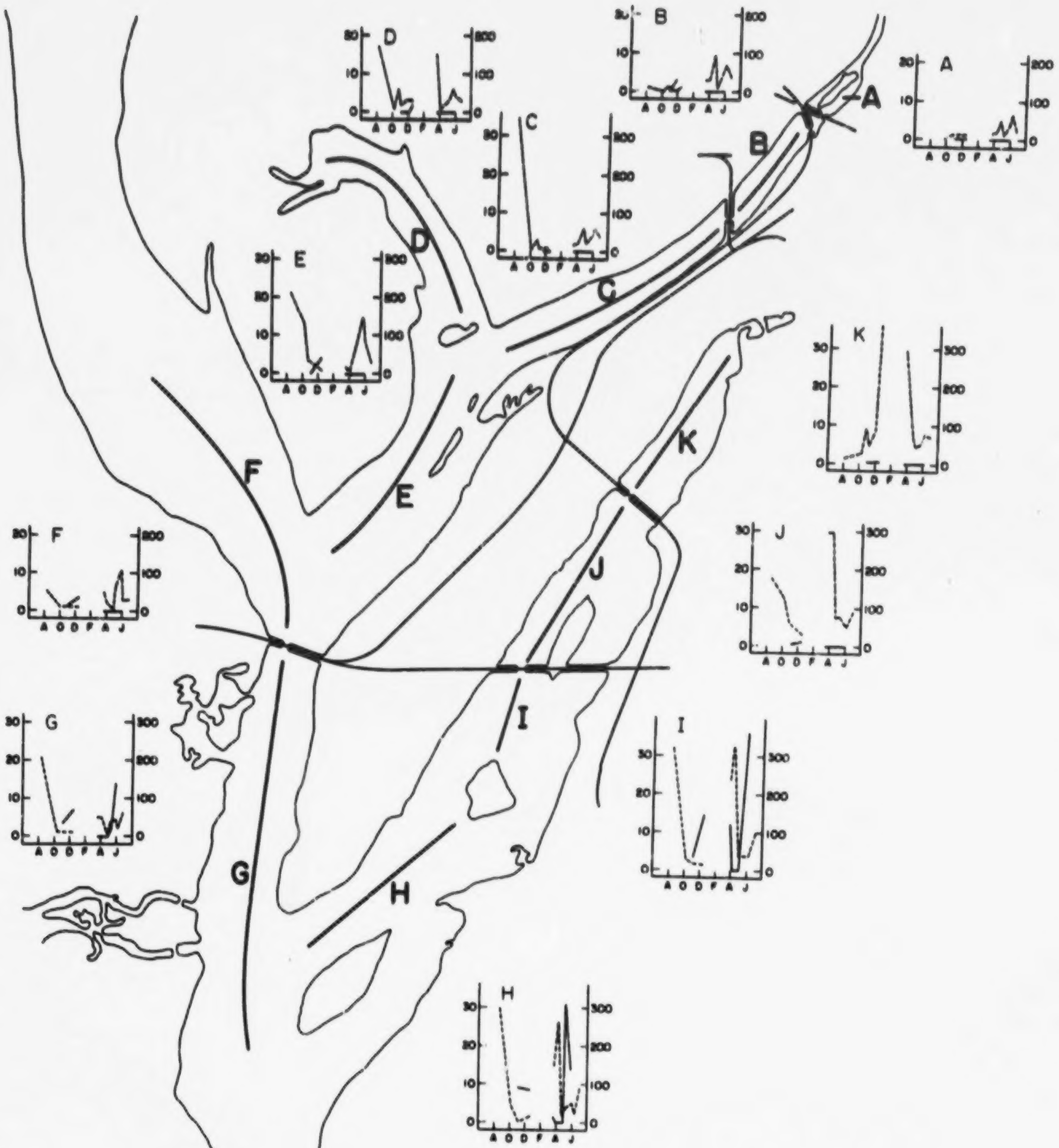

A
B
C
D
E
F
G
H
I
J
K
0
10
20
30
100
200
300
A O D F A J

Figure 7. Comparison of chlorophyll a content (at .4 m) and light intensity at 1 meter depth throughout Moses Lake during 1968 and 1969. Dashed line is chlorophyll a and solid line is estimated light intensity at 1 meter. Right ordinate in μg/l chlorophyll a and left ordinate in langleys per day light intensity at 1 meter.

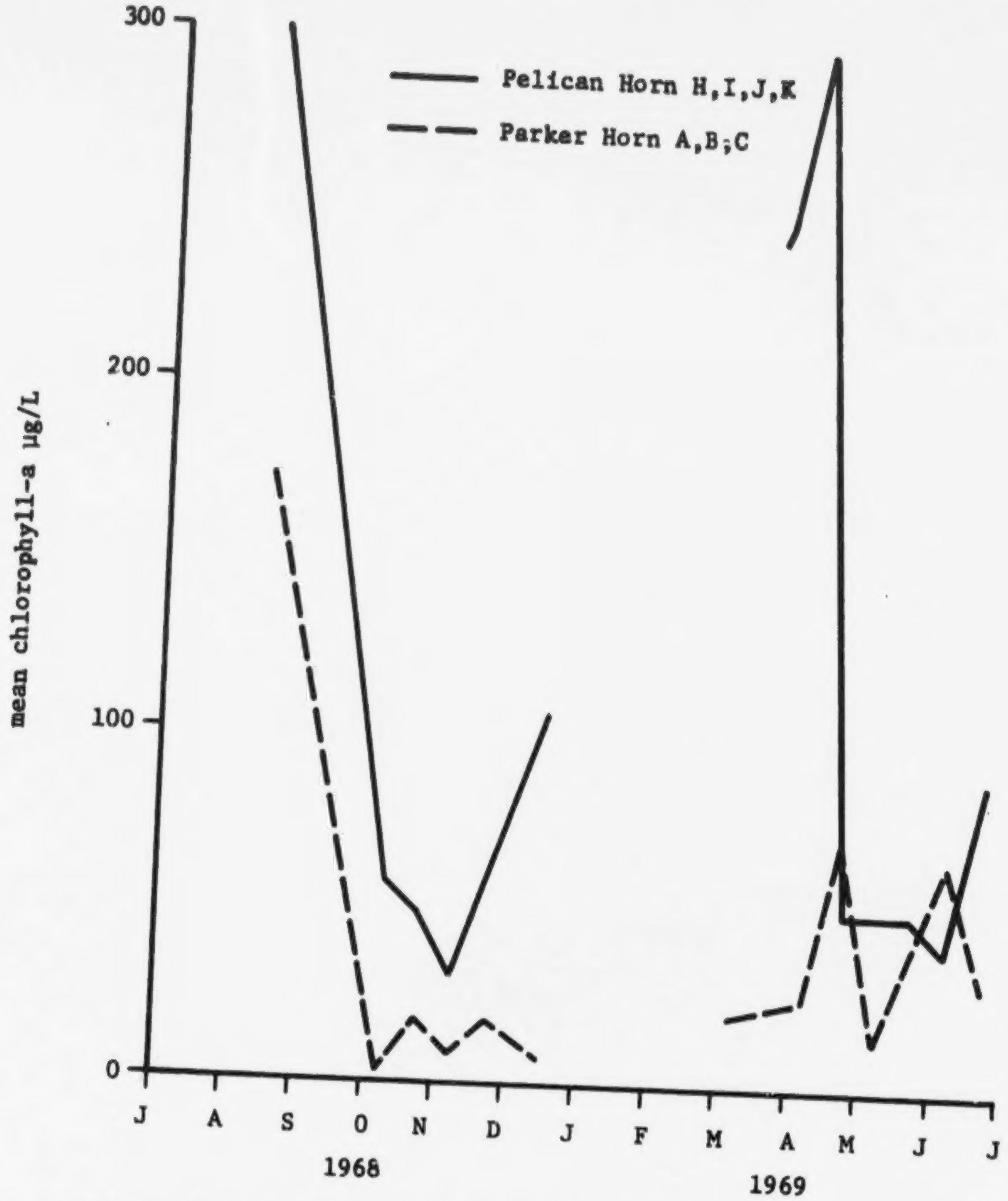


Figure 8. Comparison of mean chlorophyll a content of all stations in Parker Horn (Stations A,B,C) and Pelican Horn (Stations H,I,J,K) during part of 1968 and 1969.

the spring quantities of algae. However, as Figure 7 indicates, total intensity of light reaching a depth of 1 meter (calculated from total incident light and attenuation coefficients) was not positively related with chlorophyll a. Actually, light intensity was inversely related at station I and H, presumably as a result of the light attenuation properties of the algae themselves.

That the earlier peak in algal crop occurs earlier in Pelican Horn is also indicated by cell count data from a study in 1963 [Sylvester and Oglesby (3); Figure 9]. Comparison of algal quantities between 1963 and 1969 is not possible since only cell counts are available from 1963, and they are likely not proportional to chlorophyll a. Since quantities of green algae are usually greatest in Pelican Horn and their chlorophyll a per cell count would be low because they are mostly small cells, cell counts may have underestimated the algal crop quantity in Pelican Horn relative to Parker Horn in 1963. Figure 9 shows cell counts in Parker Horn to be greater than those in Pelican.

Whether increased flow rate out of the lake indicates reduced detention time or increased turbidity, it is interesting that algal growth in the spring of 1963 did not begin until late June, when outflow reached a low level. Throughout the growing season in 1963 an inverse relation between outflow rate and algal crop density is apparent. Note also in Figure 7 that the shape of the chlorophyll a curve in Lewis Horn (Station D), an area of probably poor flushing, follows those from Pelican Horn (Stations H - K).

Total and ortho phosphate followed a pattern in near parallel as shown in Figure 10. Values of ortho phosphate declined in May and early June at most stations to reach lows just prior to or coincident with lows in chlorophyll a. However, there is no such decline in phosphorus at Station J, near the sewage treatment plant outfall, yet chlorophyll a declined proportional to that at Stations K and H.

A good portion of the time ortho phosphate was greater than 0.1 mg P/1, an extremely high value compared to most natural waters. Values commonly ranged to over 1 mg/1 at all except the most downstream stations (G, H, I), while at J, near the sewage treatment plant outfall, the concentration at times exceeded 2 mg P/1. If algal uptake is largely responsible for these observed fluctuations in phosphorus in excess of 1 mg P/1 then a cell production of nearly 1,000 mg/1 should result (assuming cell P content of 0.1%). Total seston concentrations observed were usually much less than 100 mg/1. Nevertheless, total and ortho phosphate did decline in late May and June at nearly all stations except J near the sewage treatment plant outfall.

Results of nitrogen analyses are not sufficiently comprehensive at this time to include a complete account for study. Evidence was given by Sylvester and Oglesby (3) that NO_3-N is reduced to very low levels during periods of maximum algal abundance. Limited data during late 1968 show that NO_3-N content decreases as water nears the outlet. Concentrations progressed on August 12 from 0.85 mg/1 at Station C, to 0.35 at E, to 0.25 at F, to 0.1 at G, to 0.08 at H. Total phosphorus had varied from 0.37 to 0.63 mg/1 among the same stations. This was a period of large algal crops - chlorophyll a in excess of 700 µg/1 at station H.

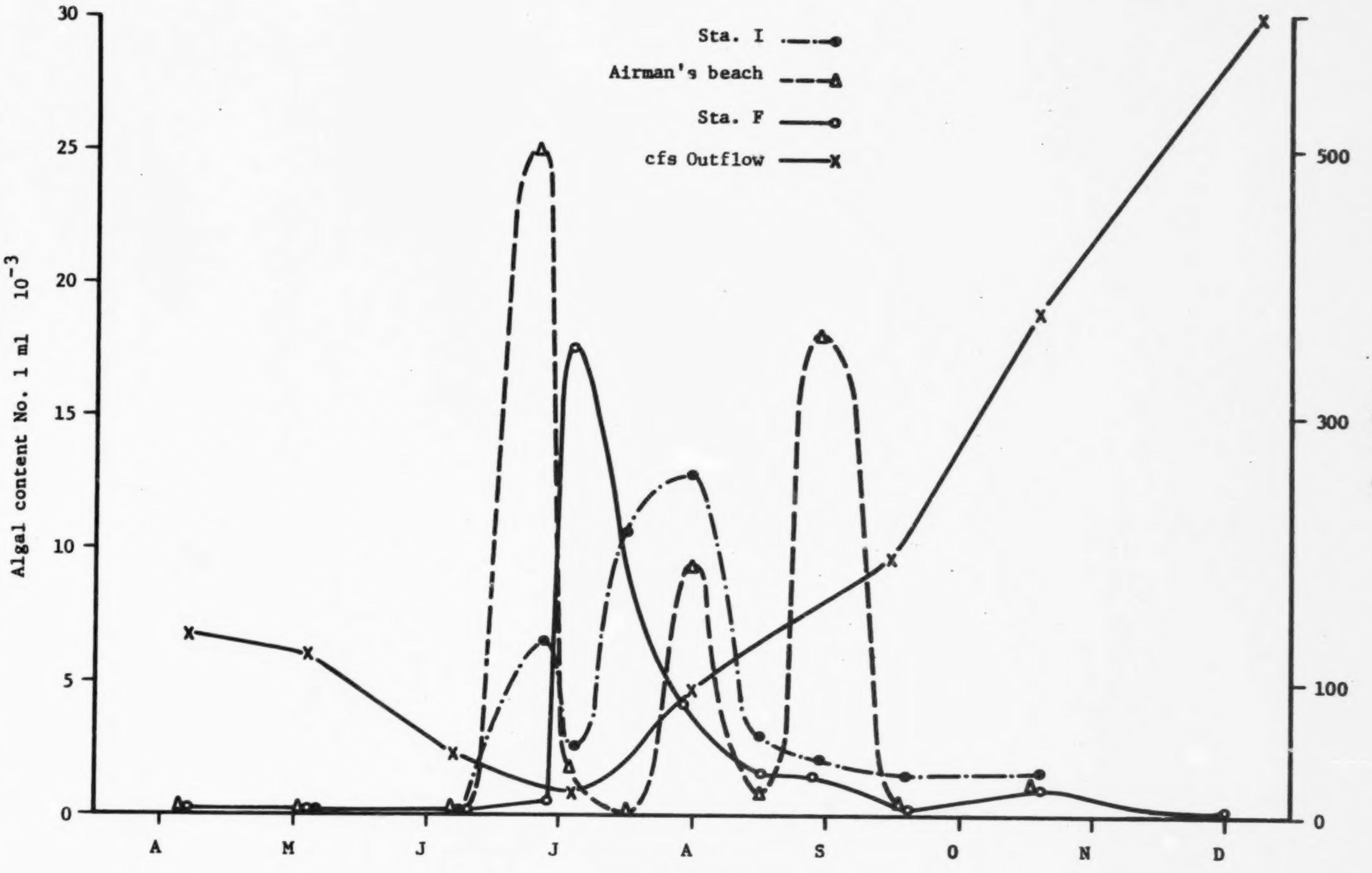


Figure 9. Relation between phytoplankton concentration in cell counts and monthly average lake-water outflow during 1963. Counts were made in samples collected from 1 meter depths at locations similar to stations in 1968-69. These data from Sylvester and Oglesby, 1963.

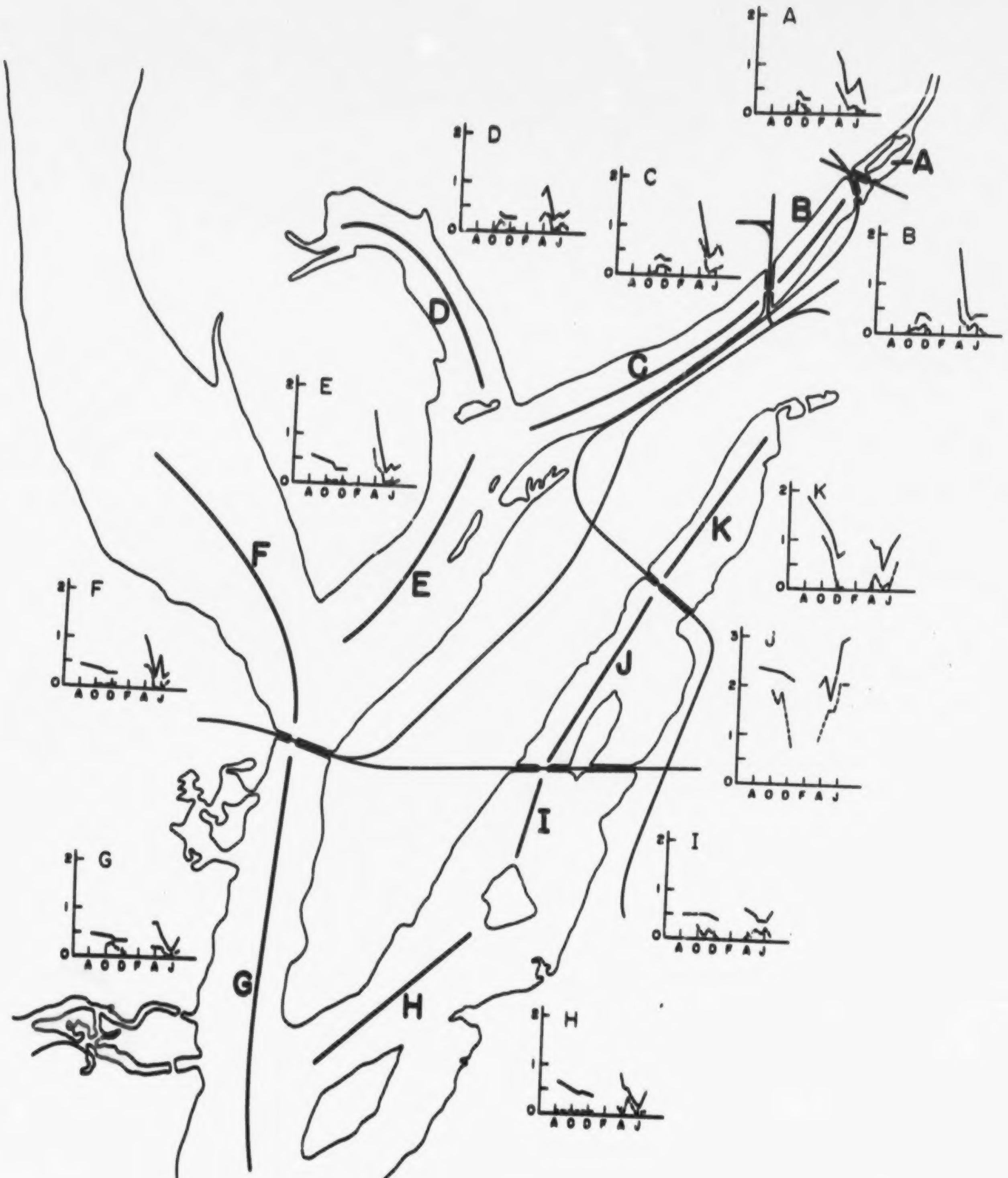

A
B
C
D
E
F
G
H
I
J
K
0
1
2
3
A O D F A J

Figure 10. Comparison of total- and ortho-phosphate phosphorus at .4 m throughout Moses Lake during 1968 and 1969. Dashed line is ortho-phosphate and solid line is total phosphate. Ordinate in mg/l phosphorus.

Because concentrations of phosphorus are usually very large, the atomic ratio of nitrogen to phosphorus is relatively low, usually less than 10/1 and occasionally 1/1 during the winter.

To compare nutrient income during this study with that recorded in 1963, the two principal surface water sources, Rocky Ford Creek and Crab Creek were contrasted with loss through the lake outlet for the two periods (Table IX). The two incoming phosphorus loads in 1963 about equaled or were a little less than the outflow load. In 1968-69, the data show that about one third of the incoming phosphorus was retained and the total income was four times the 1963 values. Runoff during the spring of 1969 was usually large. This particularly shows up in Crab Creek. It is not possible to contrast the total plankton crops during these two periods since chlorophyll *a* was not determined in 1963 and cell counts have not as yet been completed in 1968-69 samples.

The range in oxygen and thermal stratification shown in Figures 11 and 12 is typical seasonally and frequently diurnally. Thernal stratification and the associated variability can greatly affect not only oxygen content, but also nutrient distribution. Considering one station (F) during May and June 1969 the following values of phosphate - phosphorus and chlorophyll *a* occurred when the temperature profiles showed the associated surface to 10 feet temperature changes:

Date	PO_4-P (mg/l)	chlorophyll a (µg/l)	Δ°C(surface-10 ft.)
5/10/69	0.041	58	5.4
5/22/69	0.051	106	3.6
6/6/69	0.040	25	6.7
6/19/69	0.170	28	0.0

A similar trend occurs at most other stations to the extent that the greater the stratification (temperature gradient) the lower the phosphorus content in surface waters. A plot of Δ°C versus epilimnetic PO_4-P content for the available data indicates an inverse relationship, but development of such relationships, including variables expressing plankton activity, must await treatment of more complete data.

Plankton Experiments

Preliminary results are available from only two of the four *in situ* experiments. The initial experiment conducted from July 10 through 20, 1969, was designed to test the effect of dilution water on nutrient content and algal growth in plastic bags 2.8 meters deep and 0.78 m in diameter. Initially, lake water contained about 0.47 mg P/l total phosphate and East-Low canal water contained 0.03 mg P/l. Changes in chlorophyll *a* content and ortho phosphate in the bags were proportional to, but lower than, levels in ambient lake water. Total phosphate on the other hand, decreased to levels in lake water consistently less than that in any of the bags.

Effects of low-nutrient dilution water are summarized in Table X. Gross phytosynthesis and chlorophyll *a* in low-nutrient diluted water were, except

TABLE IX

Comparison of the principal parts of the phosphorus budget for Moses Lake determined in 1963-64 and again in 1968-69. Values in pounds/day as phosphate-phosphorus.

1963-1964	Rocky Ford Creek	Crab Creek	Lake Outlet
March	200	77.3	60.0
April	193.3	35.3	205
May	145.1	16.4	100.6
June	166.0	25.3	38.0
July	177.4	40.9	14.5
August	203.3	46.4	85.1
September	186.6	42.6	150.3
October	183.8	60.3	354.5
November	190.0	66.3	903.3
December	183.8	50.0	454.5
January	166.0	36.5	172.5
February	157.4	23.2	48.2
TOTALS	2152.7	520.5	2586.3
1968-1969			
August	201.9	134.2	432.8
September	237.1	104.7	604.8
October	245.7	72.6	482.8
November	186.3	46.9	717.4
December	166.3	23.2	427.1
January	166.9	53.4	287.7
February	166.9	126.9	464.2
March	193.3	4952.8	1757.8
April	178.7	1412.6	1589.9
May	247.0	244.1	468.3
June	196.0	140.9	83.6
July	185.8	78.3	299.0
TOTALS	2371.9	7399.6	6615.9

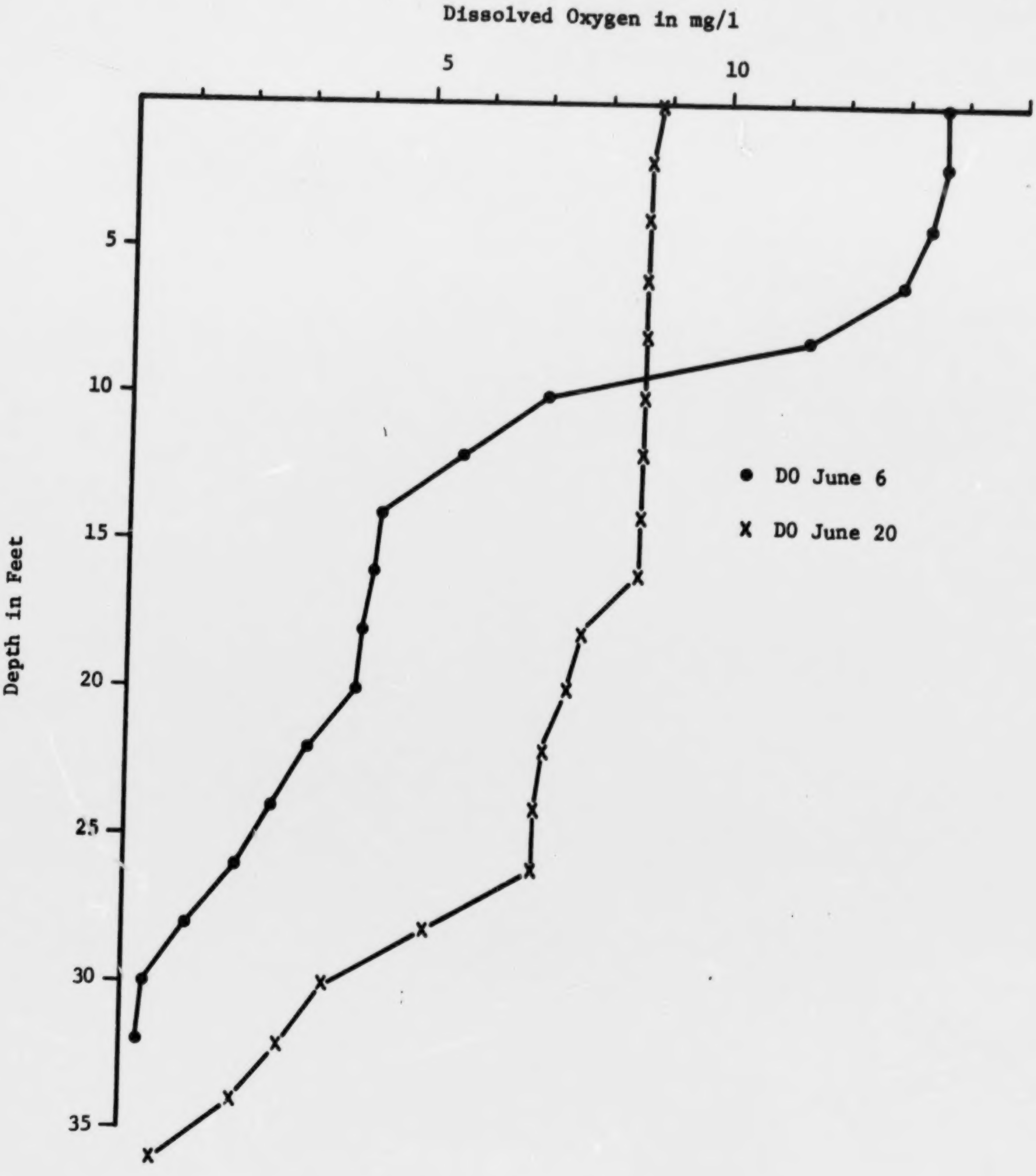


Figure 11. Dissolved Oxygen-Depth Relationships at Station G - representing periods of mixing and stratification during June, 1969.

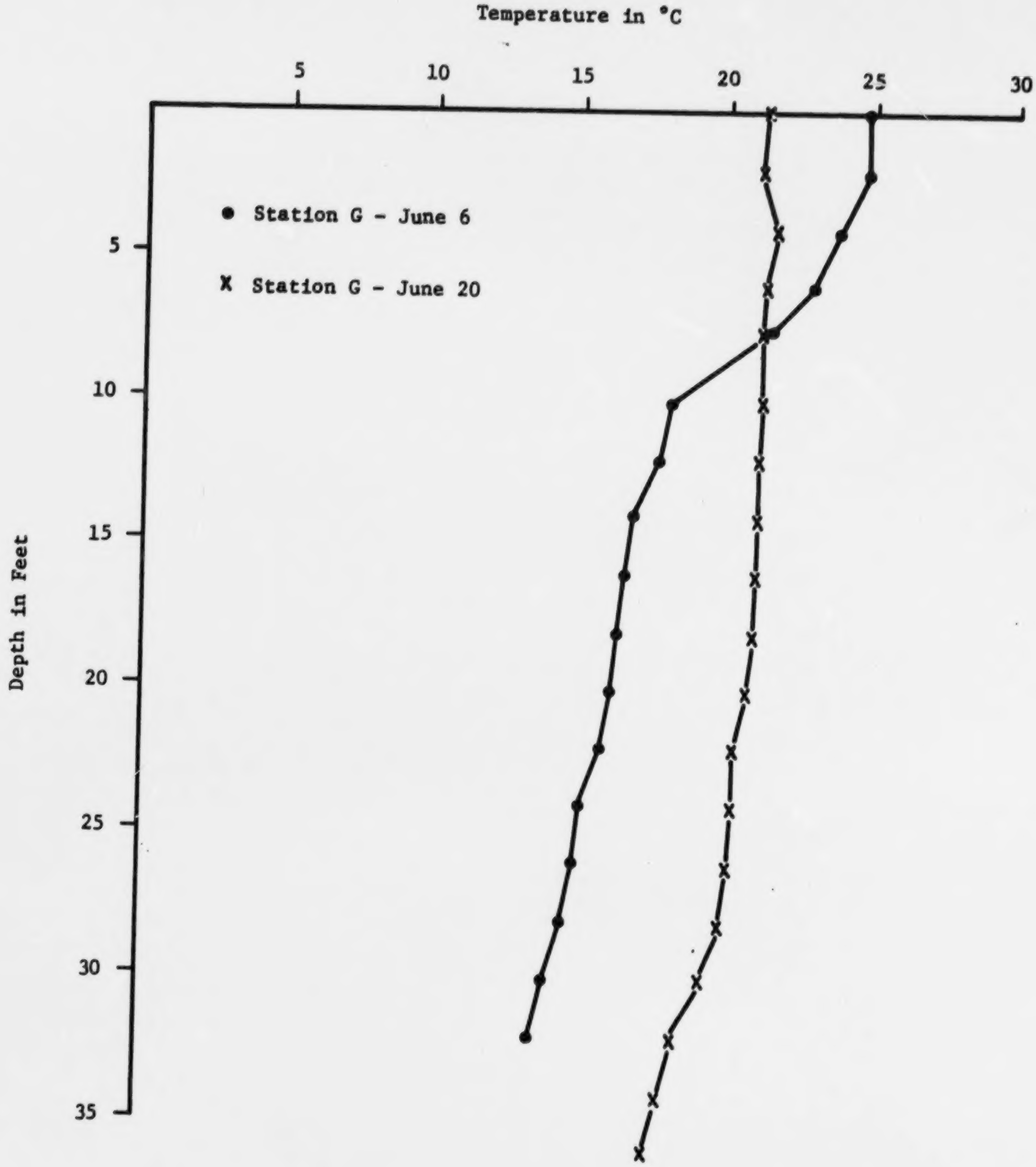


Figure 12. Temperature-Depth Relationships at Station G representing periods of mixing and stratification during June, 1969.

TABLE X. Relative chlorophyll a gross photosynthesis, total and orthophosphate as % of control. Experiment conducted in 2.8 m deep, 0.78 m diameter plastic bags from July 10 to 20, 1969.

July	10th	12th	14th	16th	18th	20th
in situ bags with:	gross photosynthesis - averaged for 1, 2, and 3 m depths					
90% Moses Lake water	41	81	69	92	55	117
86%	32	66	71	97	40	108
	gross photosynthesis - surface					
90% Moses Lake water	66	100	81	75	38	123
86%	66	91	71	83	40	125
	concentrations of Σ PO_4 - averaged for 1, 2 and 3 m depths					
90% Moses Lake water	88	86	75	80	68	106
86%	82	79	65	96	144	59
	concentrations of ortho PO_4 - averaged for 1, 2 and 3 m depths					
90% Moses Lake water	89	100	69	114	48	97
86%	77	184	73	174	89	55
	concentrations of chlorophyll a - surface					
90% Moses Lake water	41	64	72	127	58	86
86%	78	79	44	64	35	58

for a couple instances, usually less than values in the control. Only in a couple instances did values in the control exceed the test values. Thus dilution water appears to have a negative effect on algal growth.

Although variability among containers was great at times, total phosphate remained relatively constant in all containers during the 14-day test period. That is, there was not an apparent trend in levels during the period. The variation in the ambient lake water was much greater than that in the test cells. Total phosphate-phosphorus ranges during the test period were: 0.11-0.19 mg/l in the 90% dilution, 0.10-0.27 mg/l in the 86% dilution, 0.11-0.24 in the control, and 0.09-0.38 mg/l in the ambient lake water. Ortho phosphate was much less variable during the test period. Initial ortho phosphate (as P) concentrations ranged from 0.048 mg/l to 0.095 mg/l in the five test cells. The concentrations decreased rapidly at first and then tended to level off in all cells alike, until the concentration range at conclusion of the experiment was 0.007 mg/l to 0.021 mg/l.

The other experiment was designed to study the "conditioning effect" of increased aging or detention of lake water on nuisance algal growth. The data from this and the duplicate run are not worked up in sufficient detail for inclusion, but general trends in growth at the different locations are evident. A slight growth response resulted within the first two days in Crab Creek inflow water. The next downstream test point was at the upstream end of Parker Horn, just as typical lake conditions are encountered. At this point lag time of the inoculum was least and total growth greatest. From that point, the greater the distance into Parker Horn that water was collected, or presumably the greater the water age, the greater was the delay in growth response in the filtered and inoculated water. However, at all points sampled within the lake, final growth exceeded that in filtered Crab Creek water. Apparently filtered lake water is more stimulatory to lake originated inoculums than is filtered inflow water. Interpretation of these results in the light of nutrient and species composition data remains.

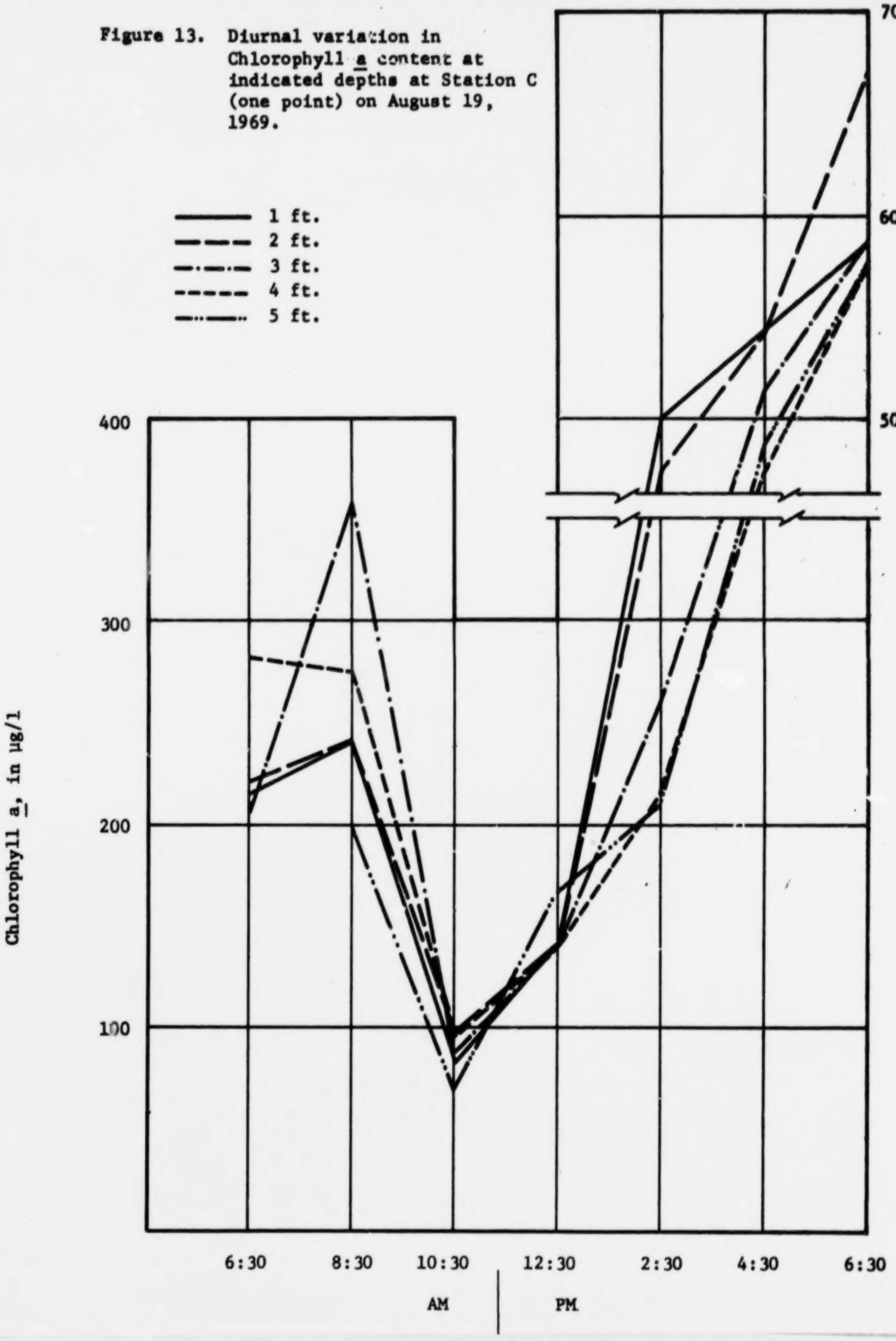
Plankton Crops and Productivity - Diurnal Variation

Chlorophyll a content varied as much as six fold during a 12 hour period at station C in Parker Horn (Figure 13). This variation occurred throughout the photic zone as a whole from 1 to 5 feet. The low values occurred at mid-morning and the highs in the evening. Sampling was not carried out over a 24-hour period so higher or lower values may have occurred then outside our sampling period. The variation did not simply result from a vertical shifting in the plankton crop; the plots of chlorophyll a with depth below the photic zone show that the change occurs throughout the water column (Figure 14). To be sure the total chlorophyll a content in a vertical water column is still least at 10:30, a time when direction of surface drift reversed, and increases towards evening at all depths except the bottom most point. Similar diurnal variation below the phtoic zone also occurred on other days (Figure 15).

Consideration of this diurnal variation in algal mass is important as it may bear on the effectiveness of flushing. Is this mass largely grown in Parker Horn or is it blown in by wind driven currents?

Diurnal changes in productivity, as measured by the light- and dark-bottle method did not follow a similar pattern as chlorophyll a content (Figure 16).

Figure 13. Diurnal variation in Chlorophyll a content at indicated depths at Station C (one point) on August 19, 1969.



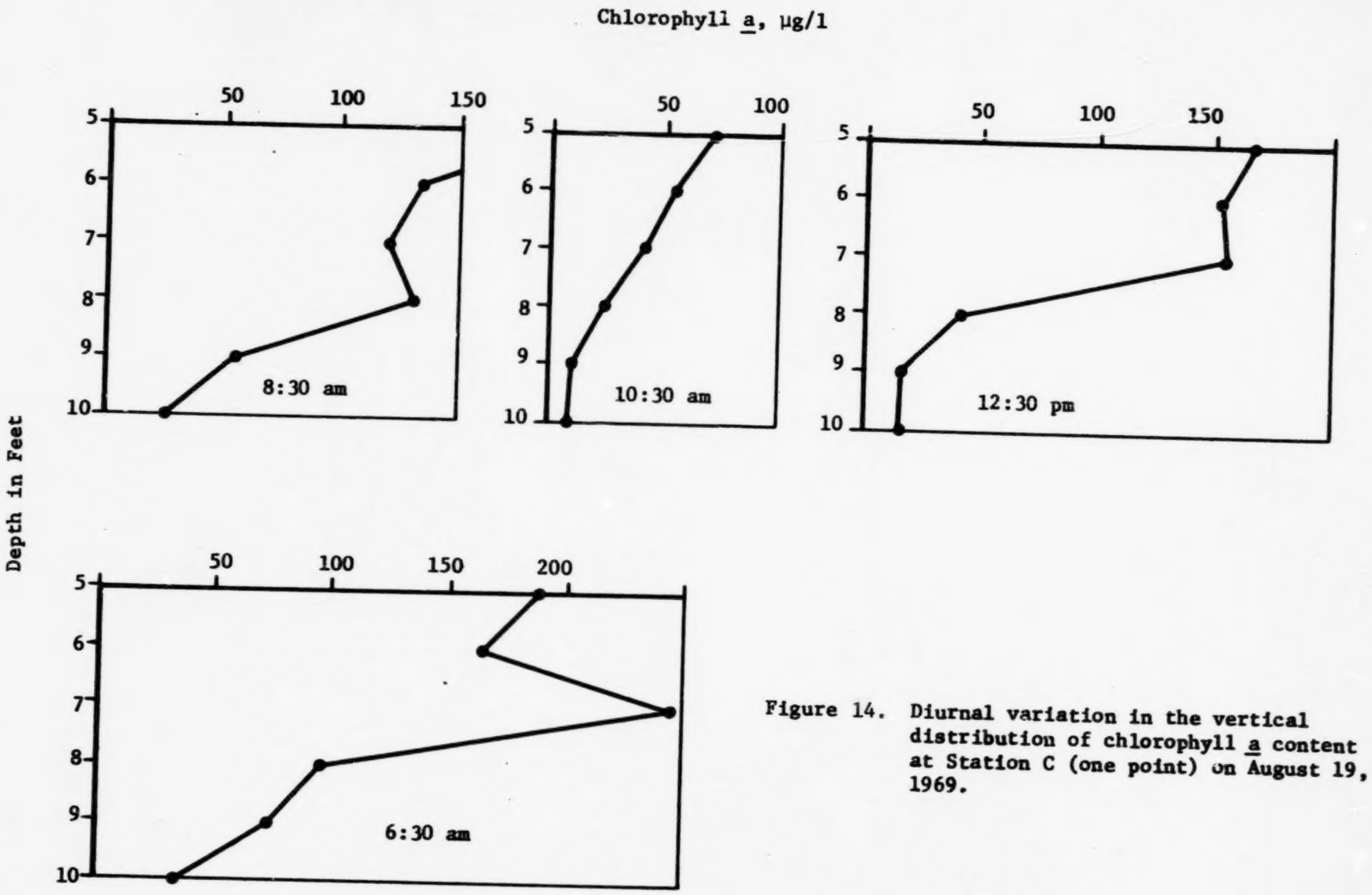


Figure 14. Diurnal variation in the vertical distribution of chlorophyll a content at Station C (one point) on August 19, 1969.

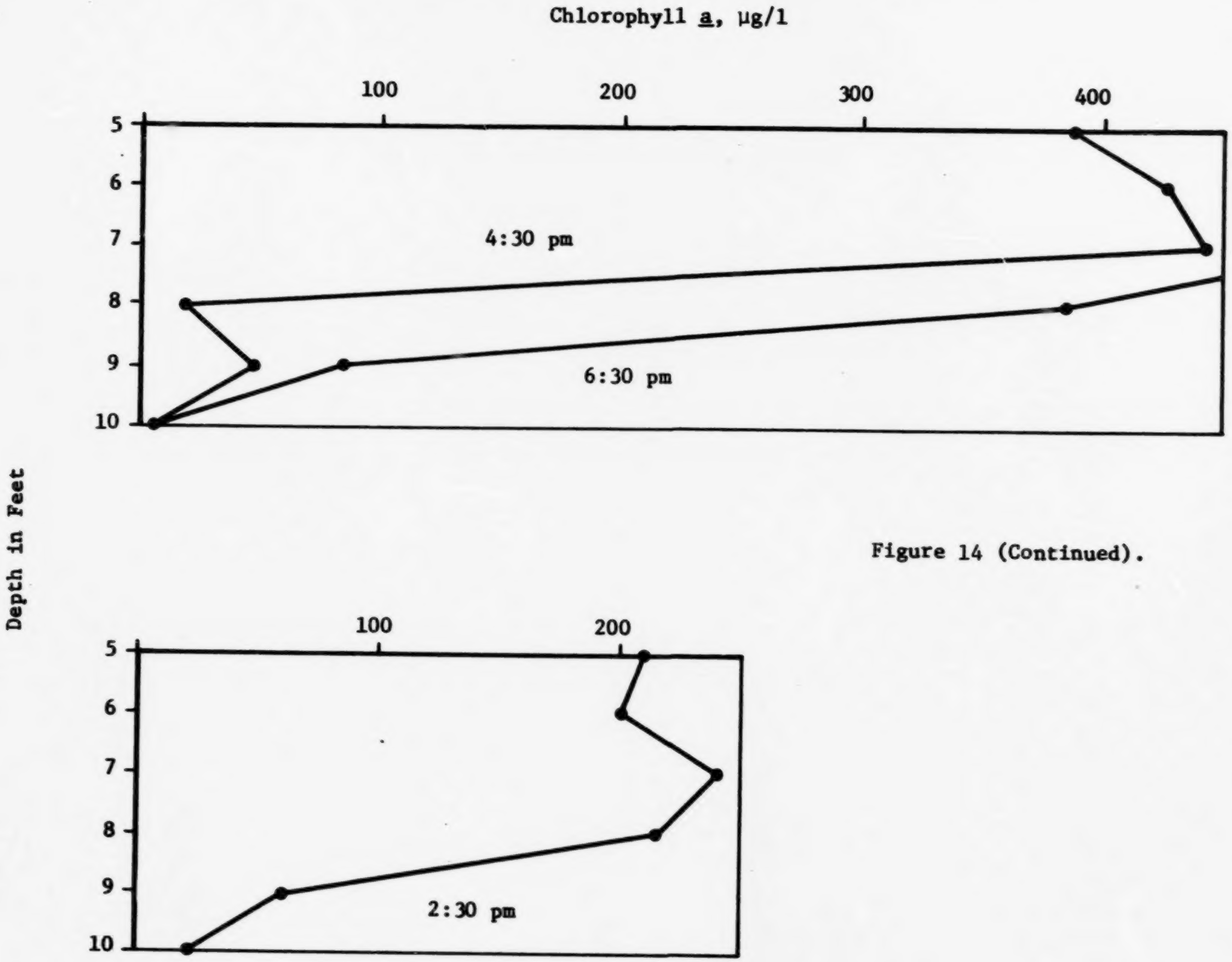


Figure 14 (Continued).

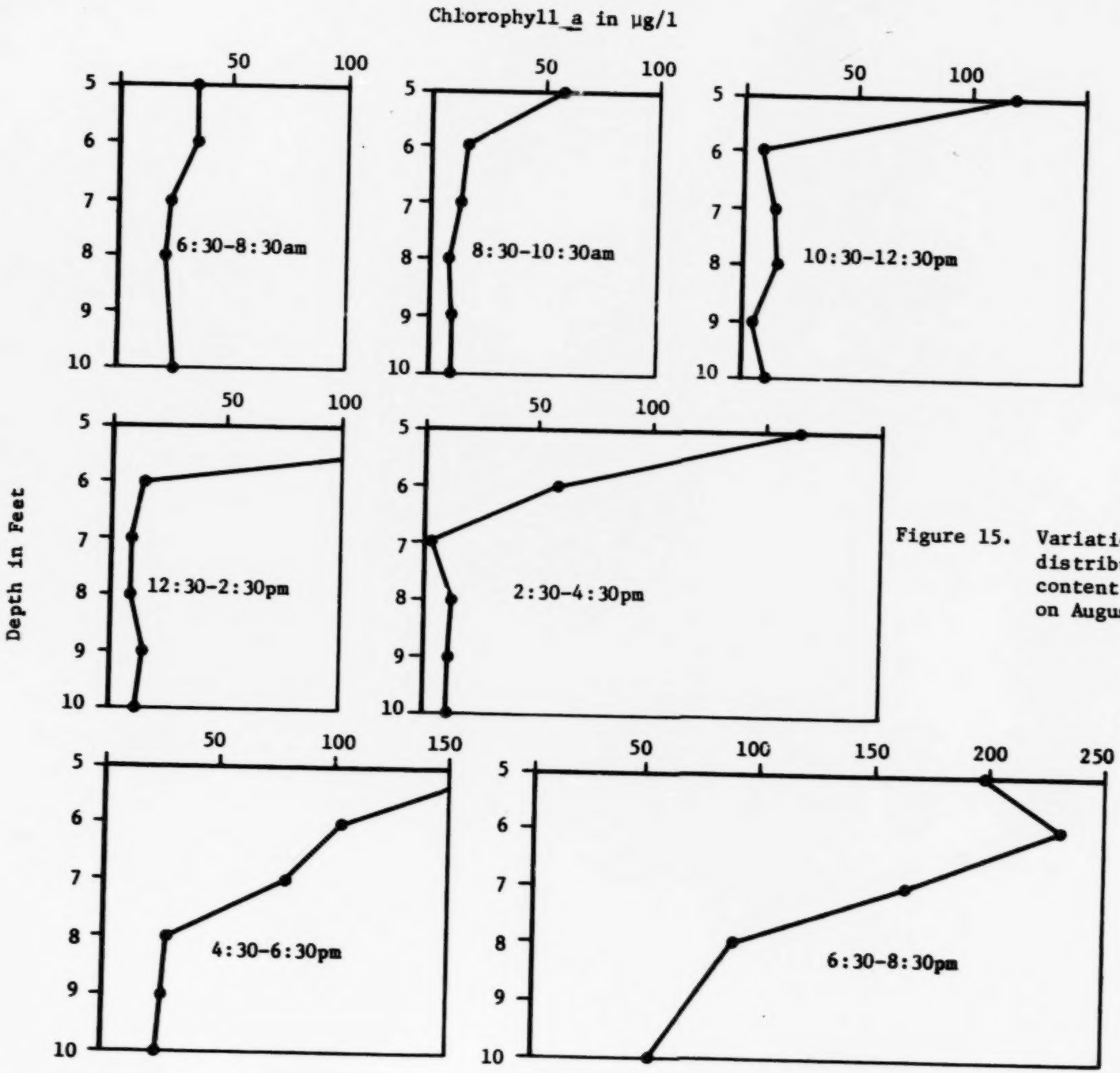


Figure 15. Variation in the vertical distribution of chlorophyll a content at station C (one point) on August 14, 1969.

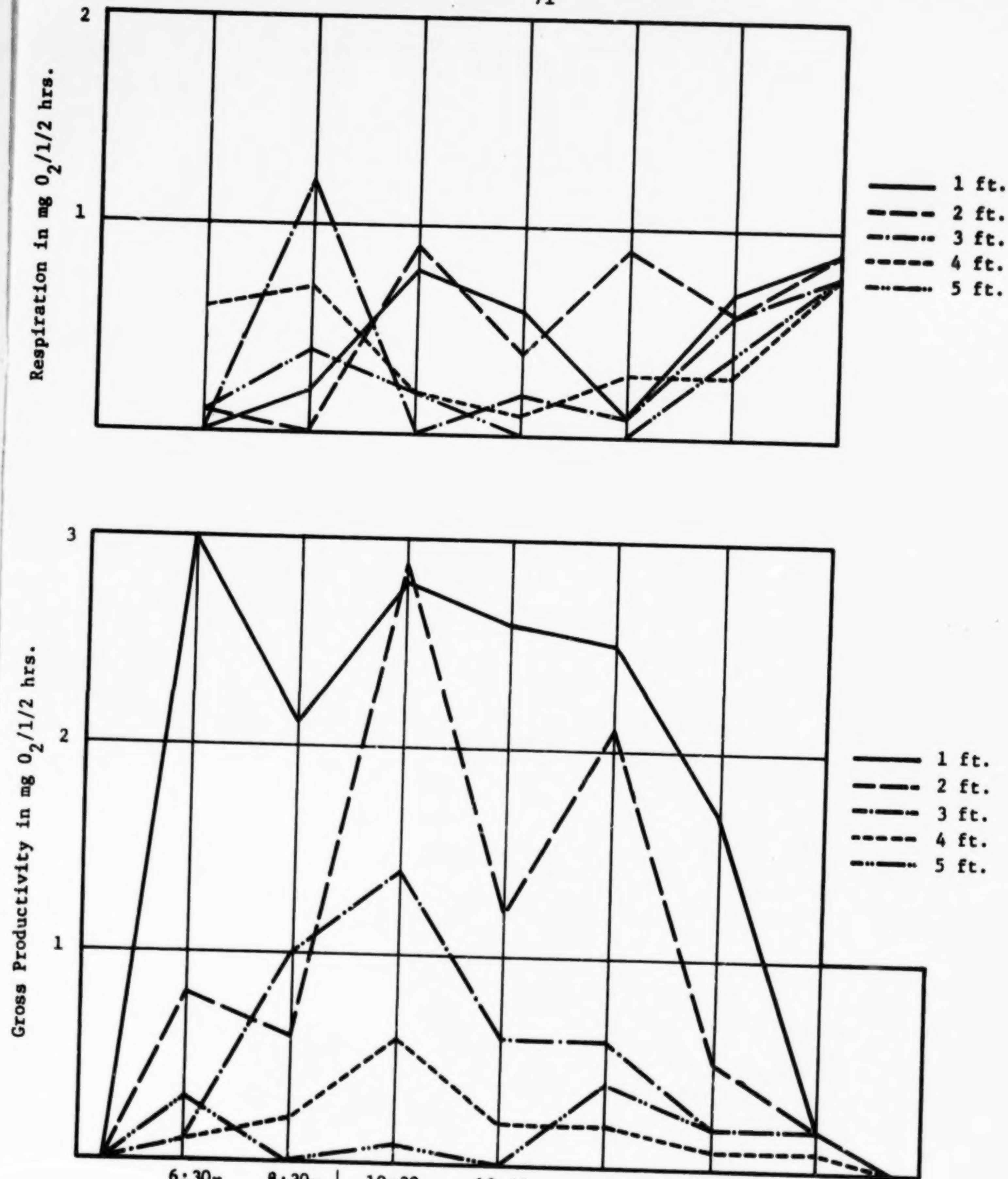


Figure 16. Gross productivity and respiration measured at 2 hour intervals and 5 depths at station C (one point) on August 19, 1969.

In fact, the highest values at most depths occurred at 10:30, the time of the lowest chlorophyll a content. An estimate of the total net productivity on August 19, from the data in Figure 16, is about 5.4 gm O_2(2gm C)/m^2/day. Dividing by a rough conversion factor for chlorophyll a of 50 gives a production of about 40 mg chlorophyll a/m^2/day. In actuality chlorophyll a content was observed to increase from about 200 mg/m^2 to over 1200 mg/m^2, an accumulation of 25 times more chlorophyll a or algal mass than is probably produced there.

By monitoring dissolved oxygen and temperature it should be possible to estimate daily productivity from diurnal oxygen rate-of-change curves corrected for diffusion. Figure 17 shows an incident light curve for July 24, 1969, along with oxygen rate-of-change curves determined from measurements made *in situ* and in light bottles. It is clear from observing monitor-recorded data that wind magnitude greatly affects mixing of the lake waters and mixing periods are easily pinpointed by changes in the vertical distribution of temperature, oxygen and conductivity. During windy conditions following relatively calm periods oxygen concentrations that were high and supersaturated would decline while bottom oxygen concentrations, previously undersaturated, would increase. Results of such a condition are shown in Figure 17. *In situ* oxygen measurements from the bottom, below the photic zone, show a large positive change in the afternoon on this date while surface waters show a negative change. Rate of change in oxygen content measured in a bottle shows an expected daily cycle. Wind apparently interacts to the extent that a diurnal accounting of the total oxygen content in the water column would be necessary to obtain a useful rate-of-change curve. Of course the use of pH as a measure of CO_2 change suffers from the same wind problem.

Some consideration was given to the use of oxygen depletion rates near the bottom, as measured by the monitor, during a period of reduced wind and increasing stratification. Respiration rates determined in bottle experiments were positively correlated with chlorophyll a content as were rates determined from the slope of the line depicting *in situ* oxygen depletion. The difficulty in using such *in situ* determined respiration rates as estimates of standing crops is the lower amounts of chlorophyll a found at the lake bottom. Considering the diurnal and vertical variability in chlorophyll a content, a continuous composite water sampler would no doubt yield the most useful information on day-to-day changes in crop in a particular area.

Hydraulic

Objectives and Emphasis of Data

The basic objectives of the hydraulic data were to provide information on patterns of water motion in the lake as these relate to factors affecting algal growths, and to provide background data for proposed flushing experiments. Specific aims were to

1) relate current patterns to inflow rates
2) relate pertinent times - through-flow, detention, and flushing - to inflow rates
3) obtain sufficiently detailed information for a limited number of inflows to provide data needed for verification of the proposed hydraulic model.

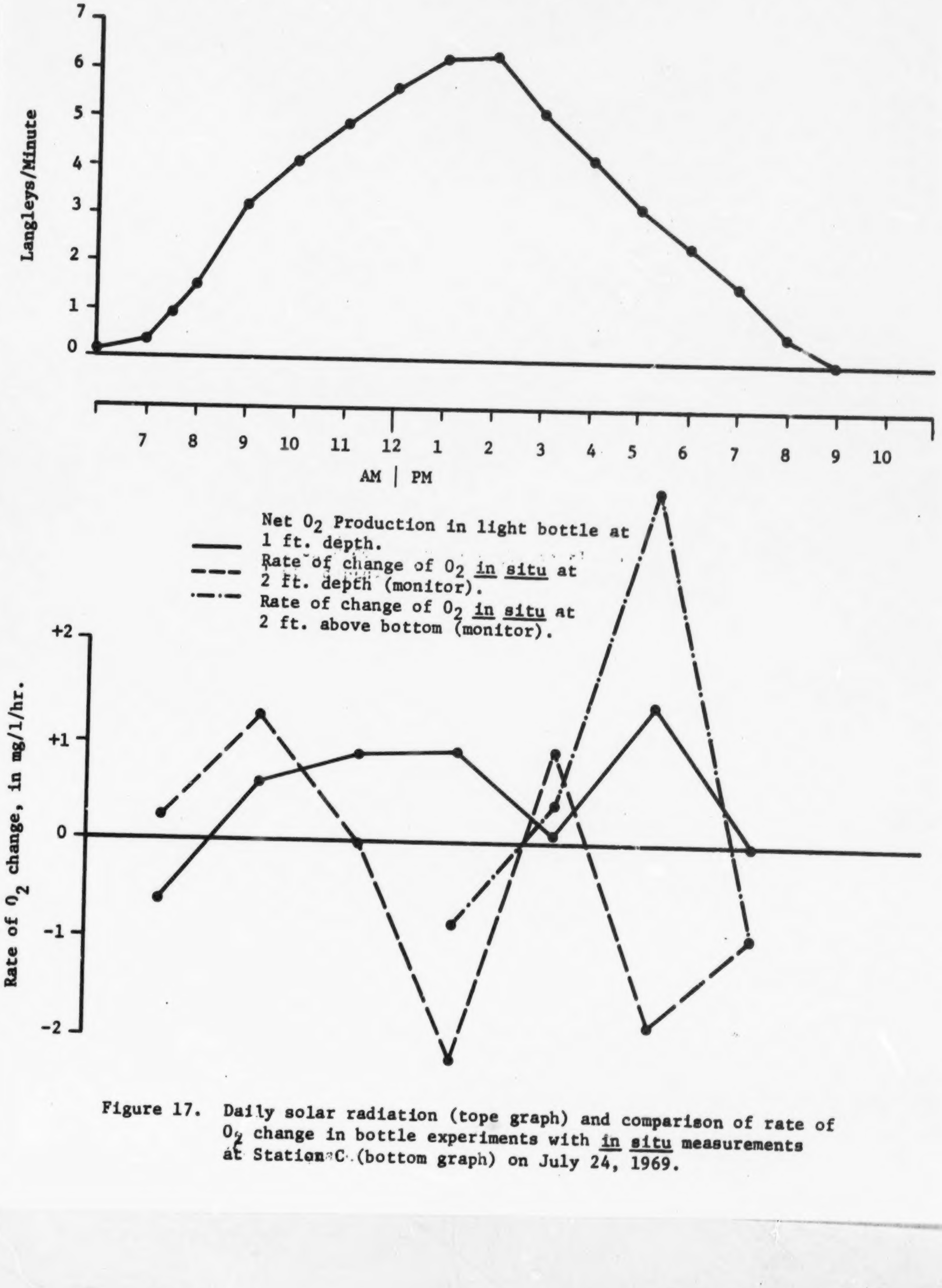


Figure 17. Daily solar radiation (tope graph) and comparison of rate of O_2 change in bottle experiments with *in situ* measurements at Station C (bottom graph) on July 24, 1969.

Hydraulic measurements were limited to Parker Horn and to its inflows. In particular, emphasis was placed on studies in the upper basin of Parker Horn, the section lying between the railroad bridge and the Alder Street causeway. The decision to concentrate efforts in the upper basin was made when the total project was curtailed; the upper basin, as a smaller and more clearly defined control volume, was more amenable to studies which could be conducted in a limited time. Further, because it is more shallow than the main part of Parker Horn, there was insignificant stratification and the basin could be considered as fully mixed. This allowed simplification in the treatment of field data and made possible the collection of data which requires less interpretation so far as future verification of a hydraulic model is concerned. This choice was made although it was realized that the upper basin, being somewhat isolated from main Parker Horn by the Alder Street causeway, was not an area in which as much might be learned about the dynamics of algal populations; hydraulic considerations governed.

Hydraulic data presented in this report are given in more detail by Holly (7). Other than two time-of-travel studies in Crab Creek made during 1968, the other field investigations reported are summarized in Table X.

Inflow and Crab Creek Data

The proposed flushing water would be added to Parker Horn through Rocky Coulee Wasteway and thence through Crab Creek. Therefore it was appropriate to investigate travel times from the confluence of the wasteway and Crab Creek to the effective upstream end of Parker Horn, selected for this purpose as the opening at the State Highway 17 bridge. Dye was dumped on the water surface, where the Crab Creek depth was about 2.5 feet. Dye concentrations were monitored at the highway bridge, samples in each case being pumped continuously through the fluorometer. The concentration vs. time curves are shown in Fig. 18 and yield the following travel times over the 1 1/2-mile distance from the drop point to the bridge:

Date	Inflow, cfs	Time of Travel, hrs
2 July, 1968	130	2.88
28 August, 1968	183	3.17

Apparently the increased inflow on 28 August caused a sufficient increase in wetted perimeter to reduce the overall average stream velocity. The inflow figures represent the sum of discharges as recorded at the USGS gaging station, "Crab Creek near Moses Lake, Washington" (2 1/2 miles upstream from the State Highway 17 bridge) and gagings of Rocky Coulee Wasteway made on the dates of the dye studies. The difference in total flow rates is too small to allow extrapolation to the larger flows contemplated for field flushing studies.

Figures 19 and 20 indicate the discharges in Crab Creek and in the wasteway, as well as the sum of the two, during the summer of 1968 and during the spring of 1969. The Crab Creek values are based on (as yet, August 1969) unpublished USGS records and current rating curve for the Crab Creek gage. Figure 21 shows a correlation between flow rates measured with the Neyrpic meter at the railroad bridge and the sum of Crab Creek (gage) and wasteway flows. Irrigation return flow accounts for most of the difference. The 6 June 1969 discharge measurement at the Alder Street bridge is considered to be low.

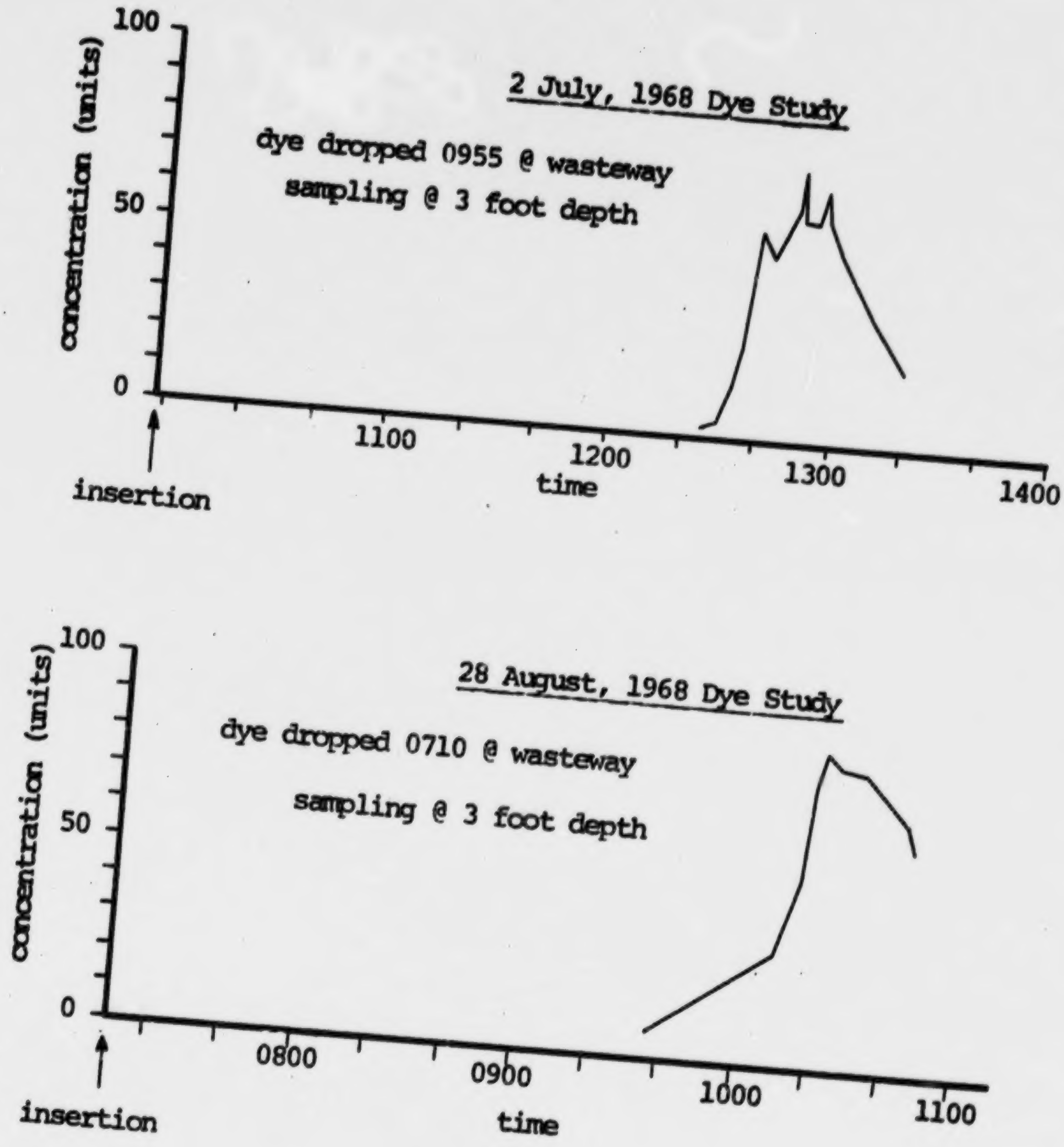


Figure 18. Time-Concentration Curves of Dye at State Highway Bridge - 1968 Preliminary Studies.

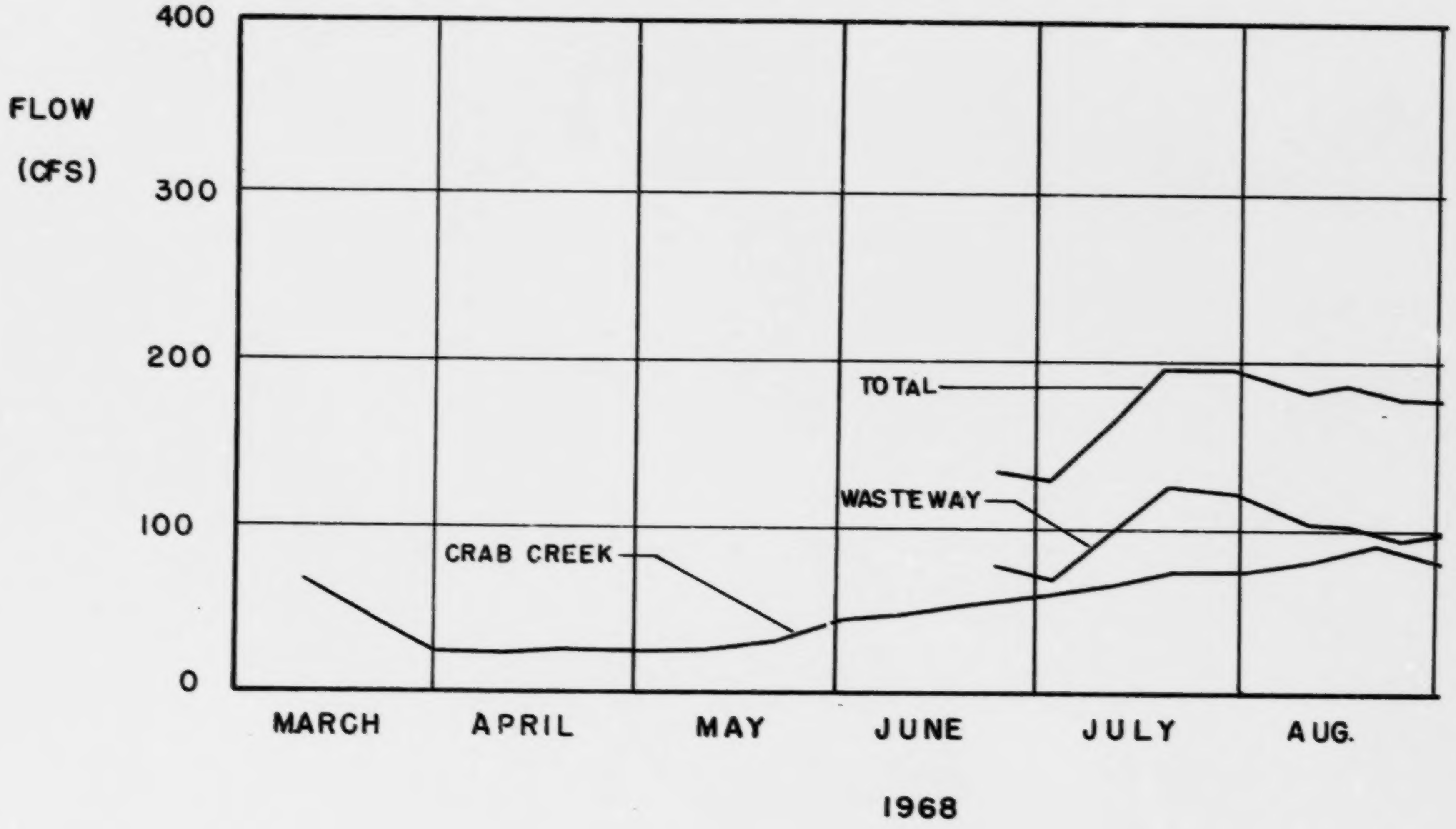


Figure 19. Crab Creek, Wasteway, and Total Inflow, 1968.

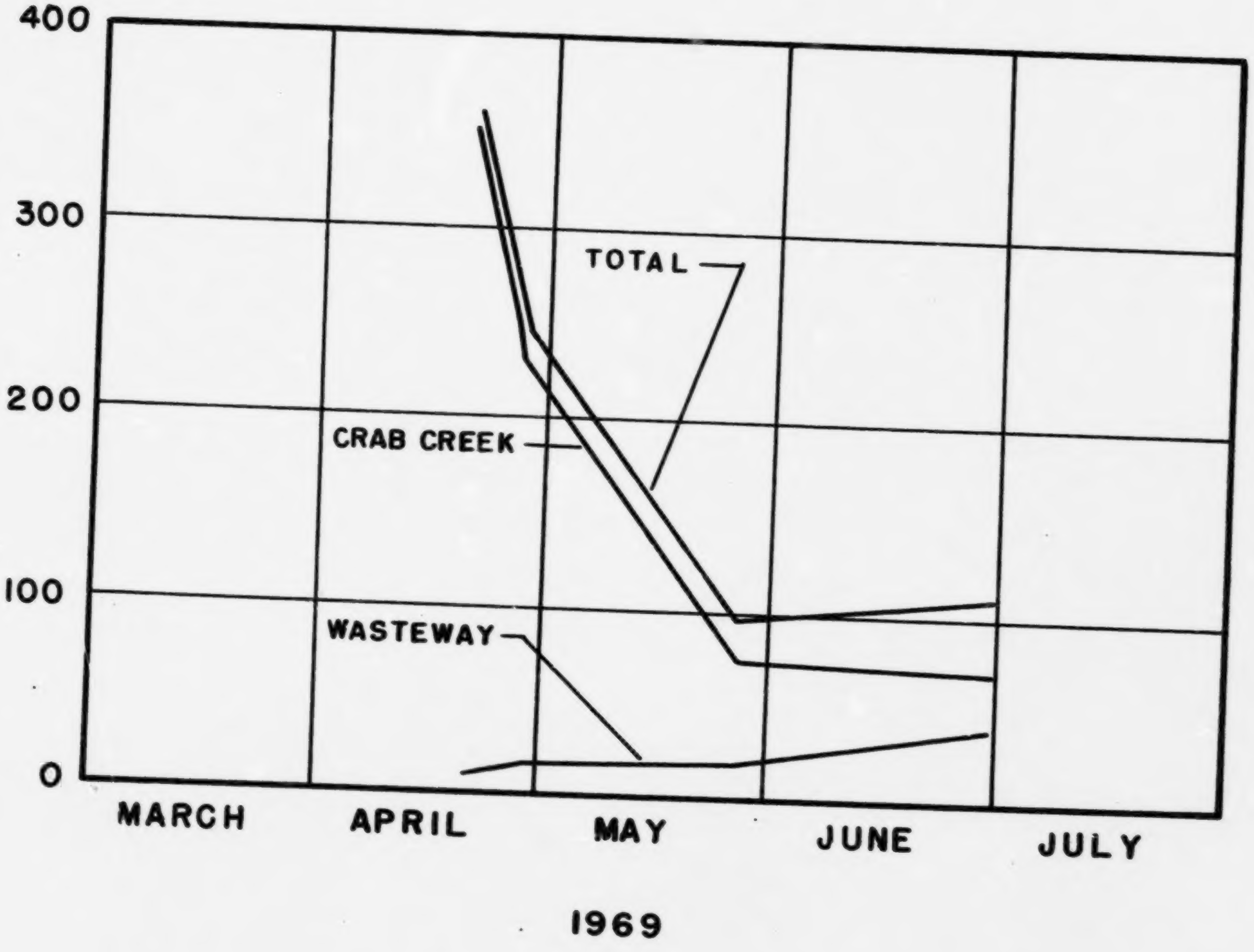
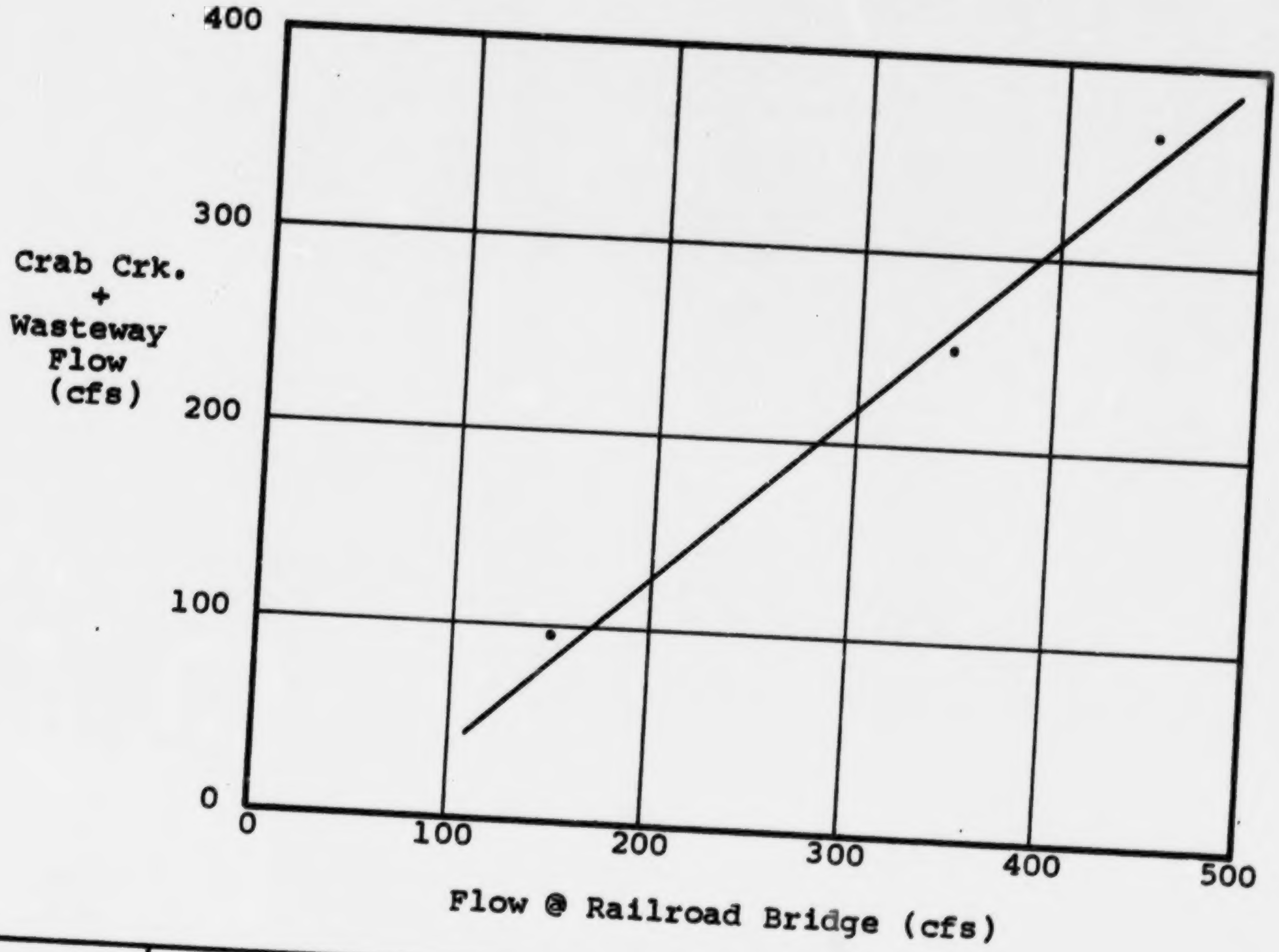


Figure 20. Crab Creek, Wasteway, and Total Inflow, 1969.



Date	Flow, cfs					$\overline{U}$**
	Crab Creek	Waste-way	Total	Railroad Bridge	Alder St. Bridge	'/s
4/19/69	352	10	362	444	-----	.56
4/27/69	230	18	248	343	-----	.44
5/25/69	73	20	93	150	-----	.21
6/28/69	67	43	110	180 *	177	.21

* estimated from correlation plot
** flow at Railroad Bridge / area of RR cross-section

Figure 21. Upper Basin Inflow Correlation.

Cross-sections through the bridge openings are shown in Fig. 22. Lake levels during 1968-1969, also taken from unpublished data provided by the Spokane office of the USGS, are given in Fig. 23. Variations in lake level about the 'mean' elevation 1046.0 are important with respect to flow characteristics in the shallow upper basin but should have negligible effect on flows in the main Parker Horn.

Time of Travel Studies, Upper Basin

Most detail in the hydraulic studies was devoted to travel time studies for the main stream, treating the opening at the railroad bridge as the inlet to the basin.

Of the three significant 'times' of interest to this study, the travel time is the only one readily measurable by techniques employed. The travel time (time required for a 'tracer' element to pass through a particular reach) provides a minimum detention time which might be experienced by a (statistically averaged) water mass moving through the same reach; the detention time is a more significant time so far as algal growths are concerned, and would be the value used in a system analysis approach in making growth predictions for the particular reach. The flushing time (required to remove all of the water in the reach at a given time and by a specified inflow) cannot be determined with much accuracy by the single-insertion dye techniques used. This point will be discussed later.

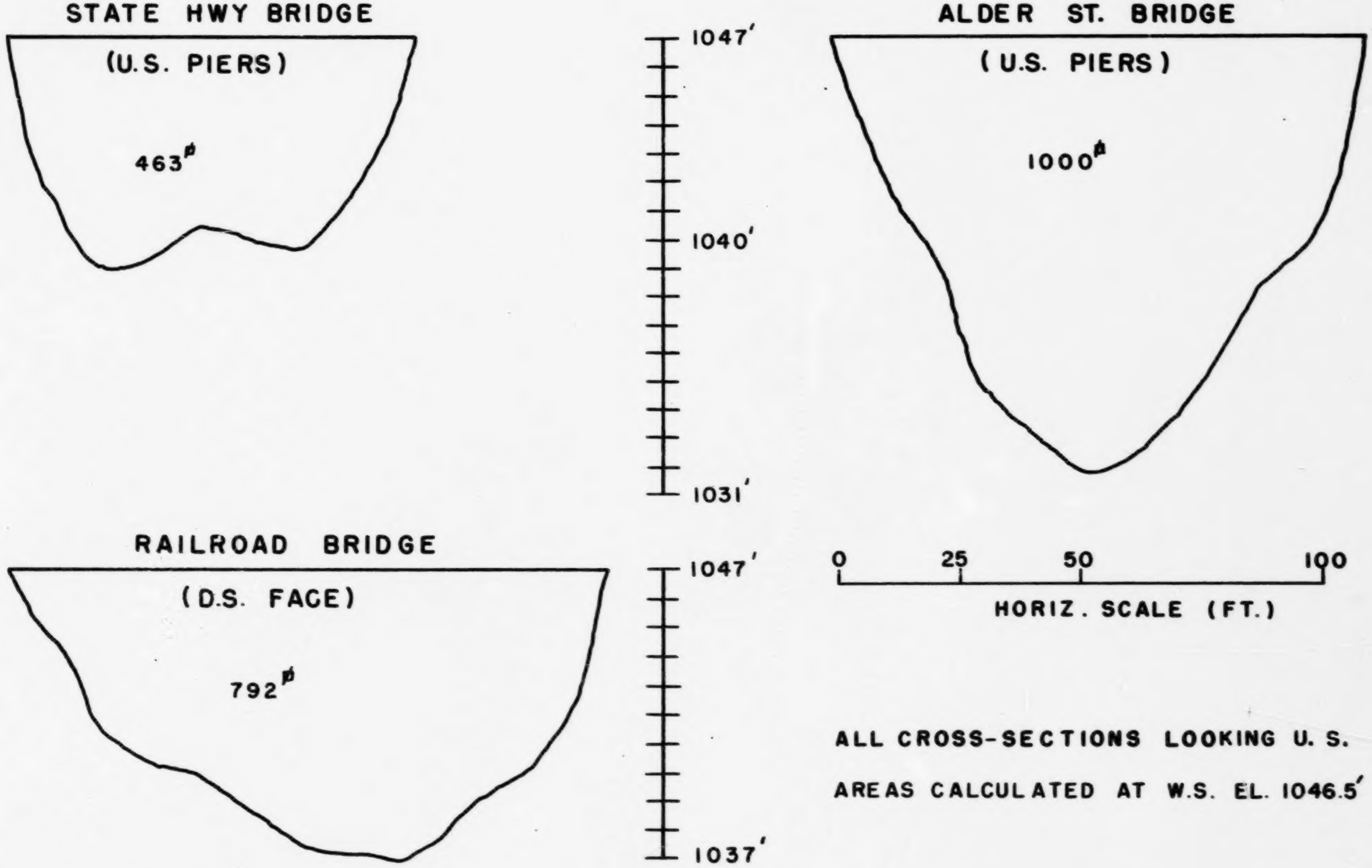
In addition to being more readily measurable, time-of-travel data could be compared with analytical models and thus provide some perspective on the application of analytical as well as physical models. Further, these specific results would provide discrete verification points for a physical model. The unstratified characteristics of the shallow upper basin removed concern over density flows there as a significant factor.

No analytical model is presently available for detailed predictions of flow characteristics in channels having the planform of the upper basin or of main Parker Horn. Although the geometries are comparable to two-dimensional abrupt expansions, the fluid mechanics laboratory studies on such flows have been limited mostly to pressure recoveries in closed ducts and are not applicable to the present case. Therefore, two models were considered as being representative of approaches applicable close to the inlet and then far downstream, respectively.

The approach considered for the area close to the inlet is the jet diffusion model of Albertson et al. (8). Because the basin is wide and shallow, application of the two-dimensional case of the Albertson et al. (8). model was attempted. The analysis assumes the flow of an initially "potential" flow jet through a slot and into an infinite quiescent fluid; turbulent flow is assumed, the diffusion process is assumed to be dynamically similar under all conditions, and the velocity distribution in the eventual fully-developed flow is assumed to be Gaussian. The analysis divides the jet into two regions:

1) initial region, in which the potential core of the jet is being eroded, and the centerline velocity is a constant, u_o, where

$$u_o = \frac{\text{discharge per unit distance normal to } \underline{\text{the plane of the velocity vector}}}{\text{slot width} = B_o}$$


STATE HWY BRIDGE
(U.S. PIERS)
463ø
ALDER ST. BRIDGE
(U.S. PIERS)
1000ø
RAILROAD BRIDGE
(D.S. FACE)
792ø
1047'
1040'
1031'
1047'
1037'
0
25
50
100
HORIZ. SCALE (FT.)

ALL CROSS-SECTIONS LOOKING U. S.

AREAS CALCULATED AT W.S. EL. 1046.5'

Figure 22. State Highway Bridge, Railroad Bridge, and Alder Street Bridge Topographic Cross-Sections.

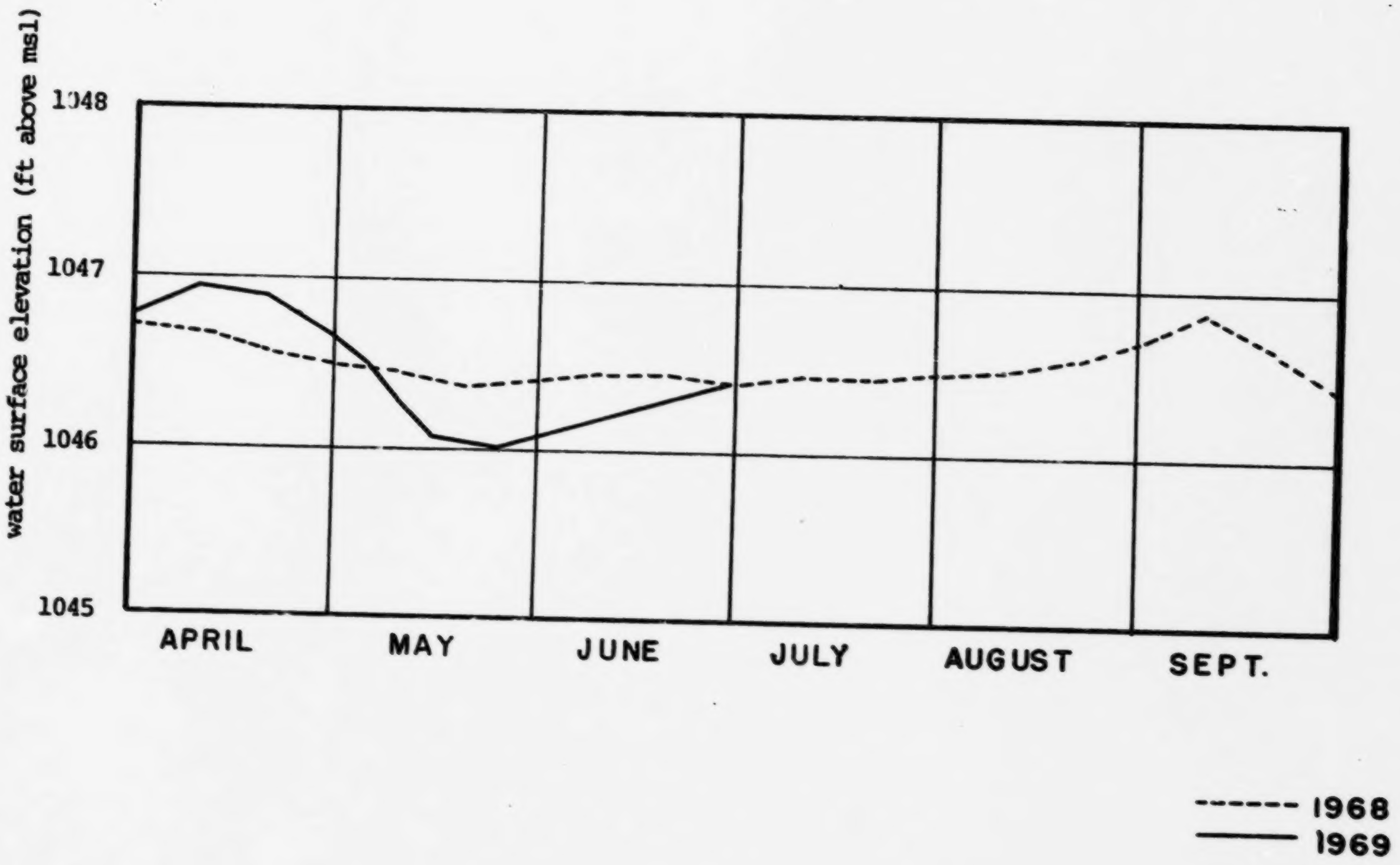


Figure 23. Moses Lake Water Surface Elevations at Interstate 90 Highway Bridge.

and which has a length of $5.2\ B_o$;

2) the region of developing flow, in which the decay of the centerline velocity u is given by

$$\frac{u}{u_o} = 2.28 \left(\frac{x}{B_o}\right)^{-1/2} \qquad \text{(A)}$$

where x is the total longitudinal distance downstream from the plane of the inlet.

Equation (A) may be integrated to give the total time of travel, T_L, over a total distance $x = L$,

$$T_L = \frac{5.2\ B_o}{u_o} + \frac{1}{3.42\ u_o\ B_o^{1/2}} \left[L^{3/2} - (5.2\ B_o)^{3/2}\right] \qquad \text{(B)}$$

Equation (B) can be applied if appropriate values of u_o and B_o are inserted. Bottom frictional effects have been ignored in the theory; a further limitation is that the presence of the confining banks coupled with the assymetry of the inflow (i.e., inflow is not directed parallel to the downstream banks) would not allow the flow to expand indefinitely as assumed in the model.

At the other end of the scale is the classical one-dimensional diffusion equation for characterizing dispersion in fully developed uniform flow in a straight duct or channel:

$$\frac{\partial C}{\partial t} + U \frac{\partial C}{\partial x} = D \frac{\partial^2 C}{\partial x^2} \qquad \text{(C)}$$

where U and C are cross-sectional means of velocity and concentration of a diffusant, respectively, and D is the longitudinal dispersion coefficient. Fischer (9) has discussed the time limits required for diffusion from a point source to take place across the entire flow section so that G. I. Taylor's analysis (Eq. A) can be applied. Fischer's analysis, which was essentially verified by his experiments in the laboratory and in the Green-Duwamish River south of Seattle, Washington, indicates that (Eq. C) can be applied only after six Lagrangian time scales, T, where the value of T is based on coupling Elder's wide-channel results for diffusion coefficients with an assumed logarithmic velocity profile in the vertical plane to yield

$$T = \frac{0.30\ (w_{max})^2}{r u_*} \qquad \text{(D)}$$

where w_{max} = effective maximum width of the stream
r = hydraulic radius (= mean depth for wide channels)
u_* = friction velocity = $(\tau_o/\rho)^{1/2}$
τ_o = boundary (bottom) shear stress
ρ = fluid density.

To utilize Eq. D, w_{max} and r can be determined from the measured channel geometry, taking effective values where the channel section is not well defined, and u* must be determined in some indirect manner. Any application of Eq. C depends upon the relationship of 6T to observed travel times through the reach under study. Considering the complexities of the field problem, consideration of any further refined analytical models was not justified.

The geometry of the upper basin is indicated in Figures 24, 25, and 26. Values of $w_{max} = 100$ feet (approximately one-half the flow width at most points) and $r = 5$ feet (approximately average depth) were selected, and $u^* = 0.04$ feet per second was taken as the friction velocity; the latter value is based on a semi-logarithmic plotting (not given here) of velocity data taken with the Neyrpic meter on 25 May, 1969. These values, when substituted into (Eq. D), yield $T = 4.17$ hours; using Fischer's analysis, Eq. C could not be used until $(6)(4.17) \simeq 25$ hours after the insertion of the tracer, a time which is roughly five times that observed as necessary for the tracer to pass through the upper basin in the 24 May field study. The estimated inflow at the railroad bridge on that date was only 180 cfs; however, even increased values of u* associated with larger flows proposed for flushing tests would still have large times T associated with them. The result is that the simplest diffusion equation (Eq. C) cannot be applied. This result also ruled out attempts to employ other diffusion analyses, and no attempts were made to use field data to determine any diffusion coefficient values. This places more weight in prediction studies of flushing operations upon empirical results obtained from a hydraulic model. Comparison of field results was made, therefore, only with the Albertson et al. model.

Time of travel data were obtained by current meter, drogue, and dye trace measurements. Drogue paths for different dates are shown on Figure 24, and the sampling locations for two sets of the studies summarized in Table XI are shown in Figures 25 and 26. Also shown on these figures are the location of the cross-sections where bottom contours were plotted.

Velocity data obtained with the current meter were integrated by steps to yield time of travel, with incremental times for travel through a particular reach based on the average of velocities measured at the upstream and downstream ends of the reach. Figure 27 shows results for two studies, using (1) average velocities over the full depth, (2) the maximum velocities observed at each station, and (3) the velocities at mid-depth. The stations selected were those having maximum velocities on a horizontal cross-section. The results on Figure 27 show similar trends; the 26 April data shows the anticipated shorter travel times associated with the higher flow than was present on 28 June. The choice of which of three particular velocities was used is seen to have significant effect upon travel times.

Drogue paths were roughly identical for various flow rates in the regions closest to the railroad bridge (say 500 feet), after which they varied, largely due to wind effects. Earlier drogues were set with vanes at a 3-foot depth, and these tended to ground if there was a breeze (prevailing wind direction opposes the direction of water flow); the 29 June drogue, set a shallow 1-foot depth below the surface, had the longest travel before grounding, again with a slight wind present. The data on Figure 28

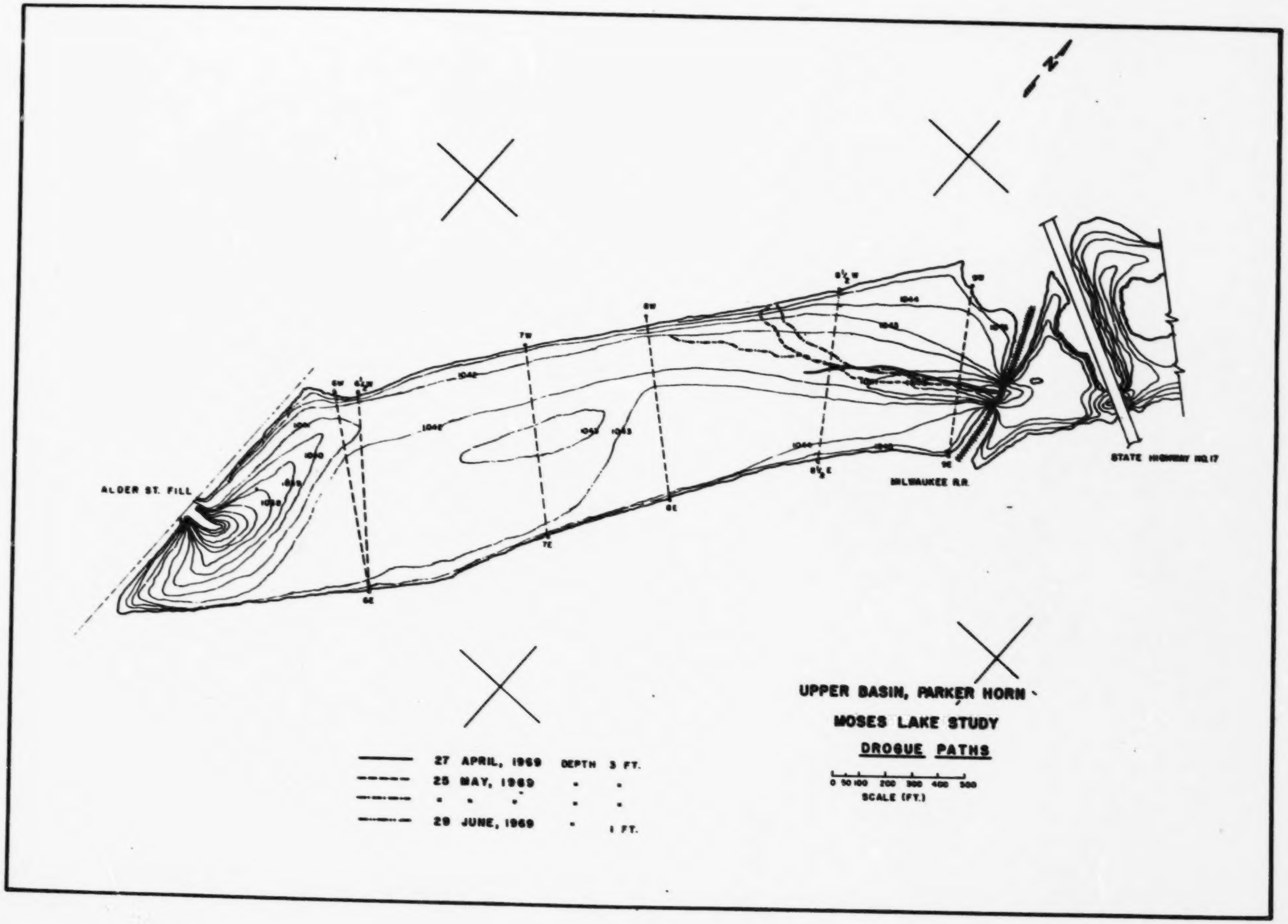

N
STATE HIGHWAY NO.17
MILWAUKEE R.R.
ALDER ST. FILL
9W
9E
8½W
8½E
8W
8E
7W
7E
6W
6½W
6E
1044
1042
1043
1040
1038
UPPER BASIN, PARKER HORN
MOSES LAKE STUDY
DROGUE PATHS
0 50 100 200 300 400 500
SCALE (FT.)
27 APRIL, 1969 DEPTH 3 FT.
25 MAY, 1969 " "
" " " " "
29 JUNE, 1969 " 1 FT.

Figure 24. Drogue paths.

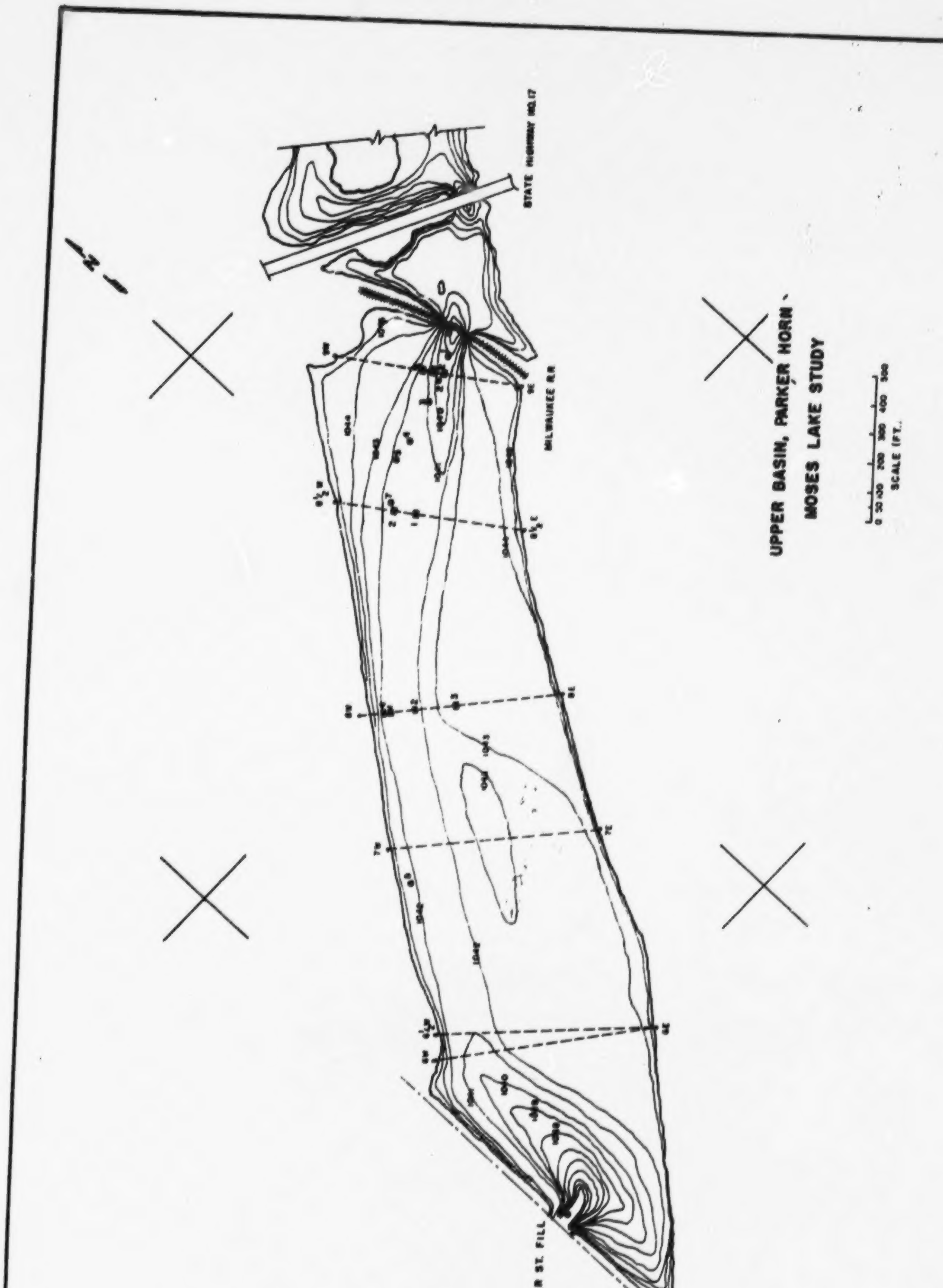

STATE HIGHWAY NO.17
MILWAUKEE R.R.
ALDER ST. FILL
N
UPPER BASIN, PARKER HORN - MOSES LAKE STUDY
0 50 100 200 300 400 500
SCALE (FT.)

Figure 25. Data collection points 24, 25 May, 1969.

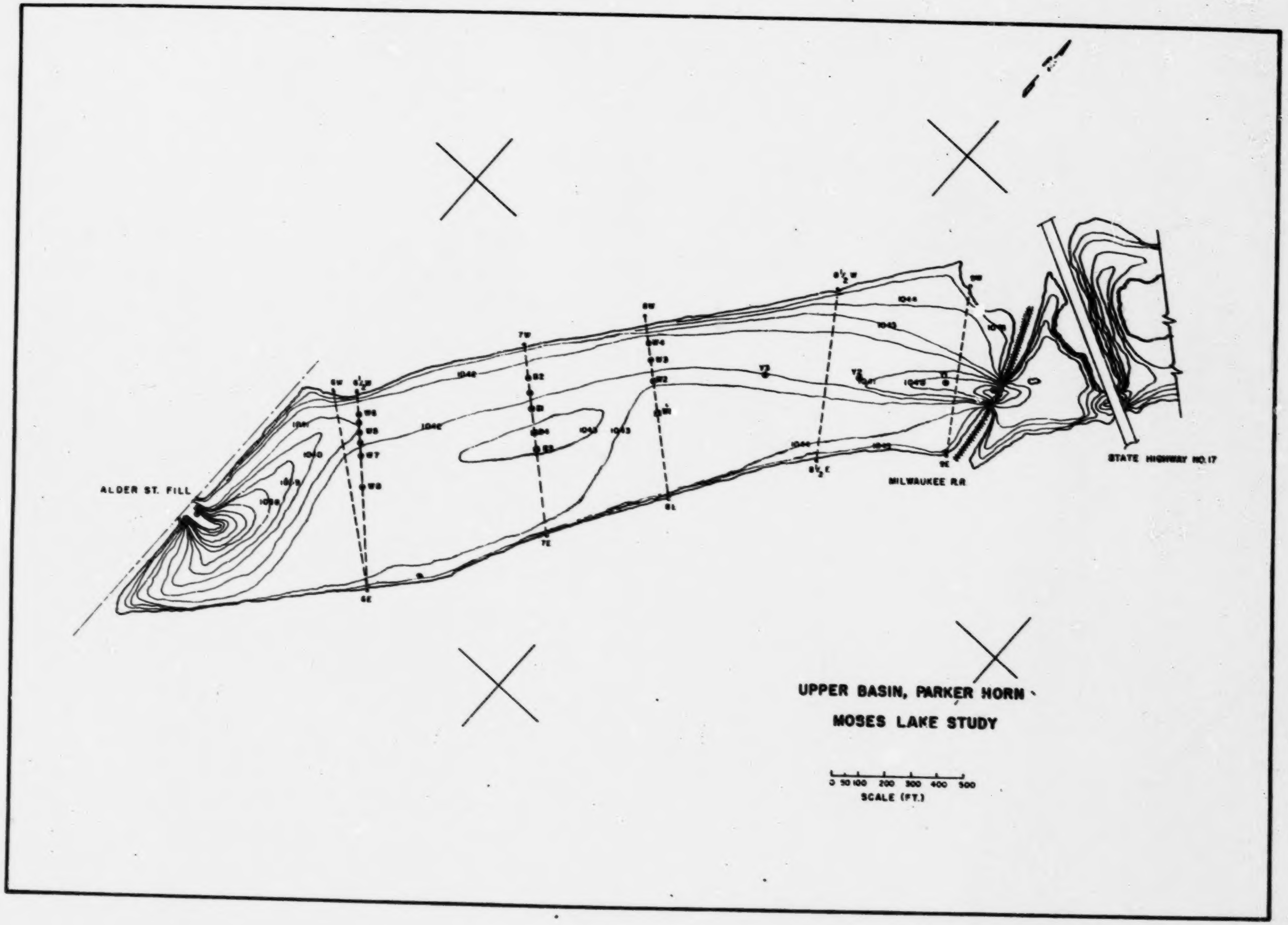

ALDER ST. FILL
6W
6½W
6E
W6
W5
W7
W8
1041
1040
1039
1038
1042
7W
7E
B2
B1
B4
B3
1043
8W
8E
W4
W3
W2
W1
V3
8½W
8½E
V2
V1
9W
9E
1044
1045
MILWAUKEE R.R.
STATE HIGHWAY NO.17
UPPER BASIN, PARKER HORN
MOSES LAKE STUDY
0 50 100 200 300 400 500
SCALE (FT.)

Figure 26. Data collection points 28, 29 June, 1969.

FIELD STUDY	15,16 Aug., 1968	19 April, 1969	26 April, 1969	27 April, 1969	24 May, 1969	25 May, 1969	28 June, 1969	29 June, 1969
Read Crab Creek Staff	✓	✓	✓	✓	✓	✓	✓	
Gauge Wasteway	✓	Estimate		✓		Estimate	✓	
Gauge RR Bridge		✓		✓		✓		✓
Gauge Alder Street Bridge								✓
Velocity Profiles @ Cross-Sections	✓		✓	✓		✓		✓
Drogue Study				✓	✓	✓		✓
Dye Study					✓		✓	

TABLE XI. Summary of Field Studies.

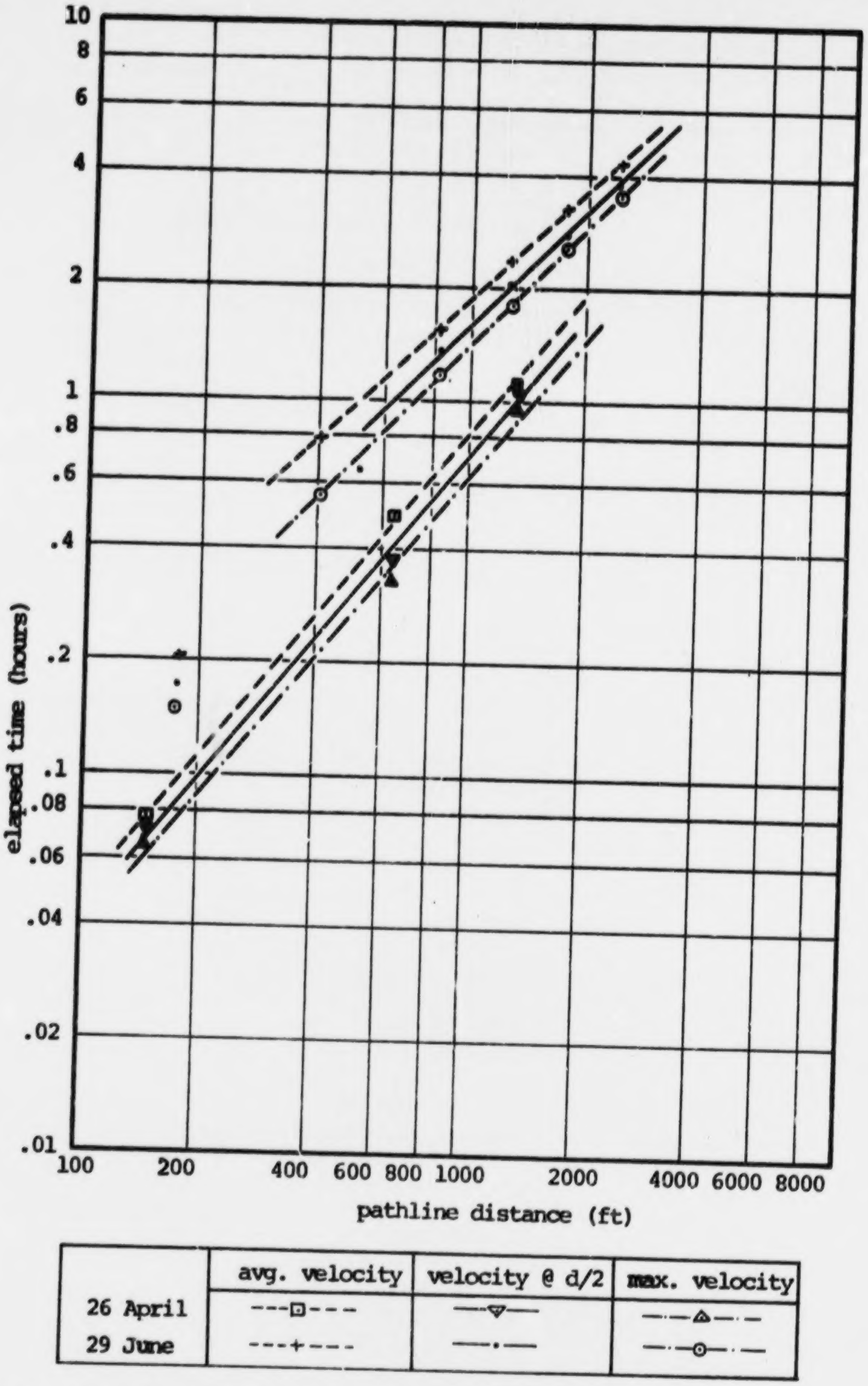


Figure 27. Integrated Velocity Time-of-Travel from Railroad Bridge.

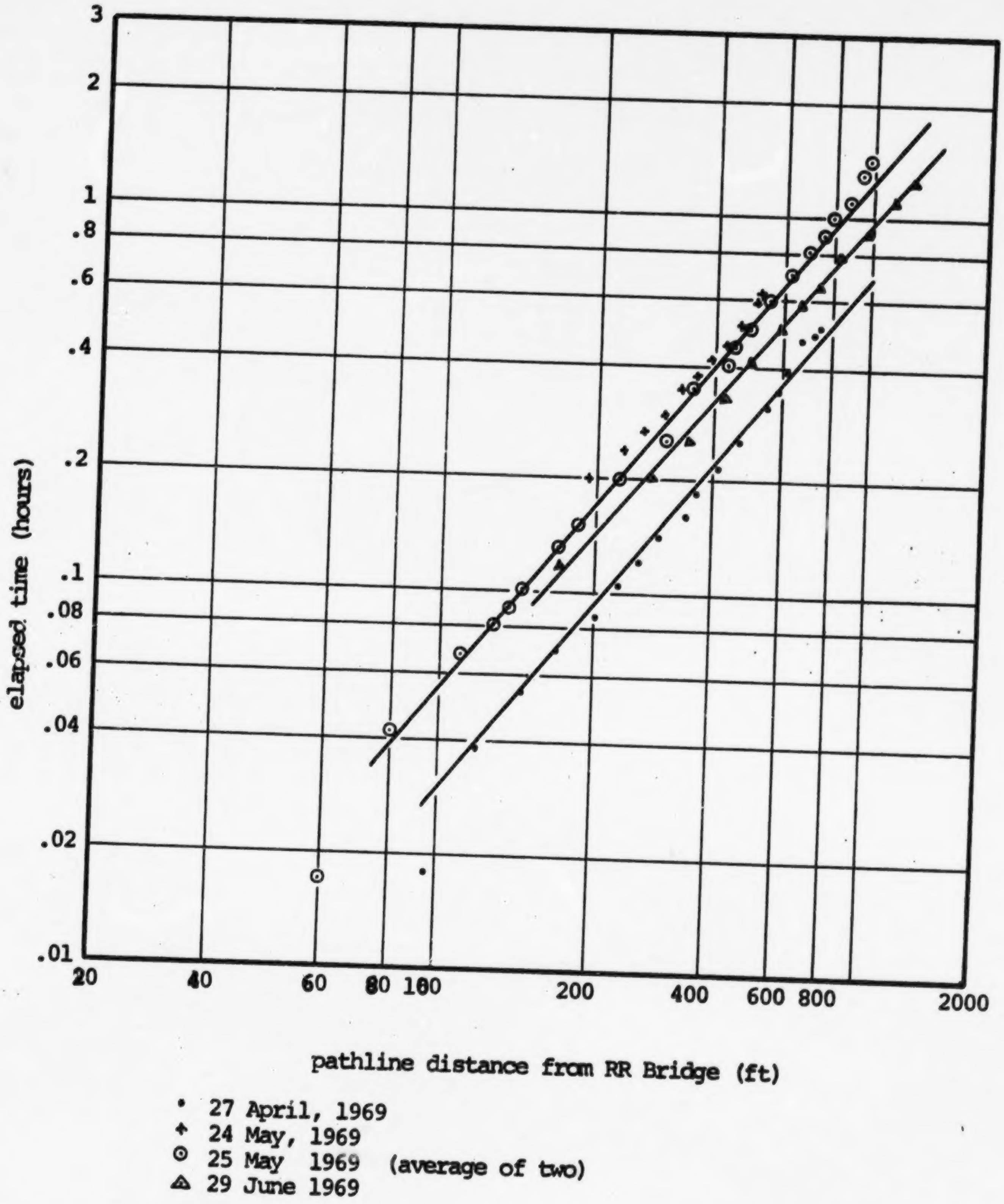


Figure 28. Drogue Study Time-of-Travel from Railroad Bridge.

were plotted using pathline distances and the times at which drogue sightings were made. Drogues in all cases were released from the railroad bridge.

Figure 29 presents the time of travel data for two dye studies. Pathline distances were measured for the path taken by the dye front, and the elapsed time is the time of passage of the peak concentration at a station from the time of peak concentration at the railroad bridge. Time-concentration curves for the 24 May 1969 test are plotted in Fig. 30; the longer travel time of the higher discharge of 28 June is verified by the drogue data of Fig. 28; this somewhat unexpected result may in part be due to changes in lateral velocity distribution and in part to the increased lake level.

Figure 31 presents a comparison of travel times as measured by the three techniques for the 28-29 June 1969 tests. The drogue results are anomolous, and the discrepancy is not readily explainable. The current meter and dye results are quite comparable, and are in good agreement over the upstream half of the upper basin with the values predicted by the jet diffusion model using Q (discharge through railroad bridge) = 180 cfs, u_o = 0.24 feet per second based on a 760 square foot cross-section area, and B_o (effective slot width) = 100 feet.

The acceptable agreement among the various field techniques suggests that any one of the three could be used as a sole index for travel times measured at times of higher flows. Again, the range of discharges covered by the field tests is too small to allow extrapolation, and the effect of lake level on results would have to be determined by future field or model studies. The travel time results give verification points for a physical model, as indicated earlier.

Flushing Times

The two most 'downstream' points on the dye time-of-travel curves of Fig. 29 represent times of passage for peak concentrations from the railroad bridge to Alder Street. These results are summarized here:

Date	Inflow, cfs	Time of Travel, hrs
24 May 1969	150	5.4 (approx)
28 June 1969	180	2.8 (approx)

The apparent anomoly in these results has been discussed above, and another field check should be made.

However, these "through flow" times provide minimum values for flushing operations. The dye measurements were made at points of peak concentration of the various longitudinal stations and the decay of measured concentrations as shown in Fig. 30 is indicative not only of mixing between the inflow and water originally in the basin but is due more to longitudinal dispersion of the tracer.

The more conventional lower time limit required for flushing (i.e., replacement of the volume of water in the basin) is computed on gross flow basis. Using as the inflow Q = 180 cfs, and taking the upper basin volume as 180 acre-feet, the calculated detention time is approximately

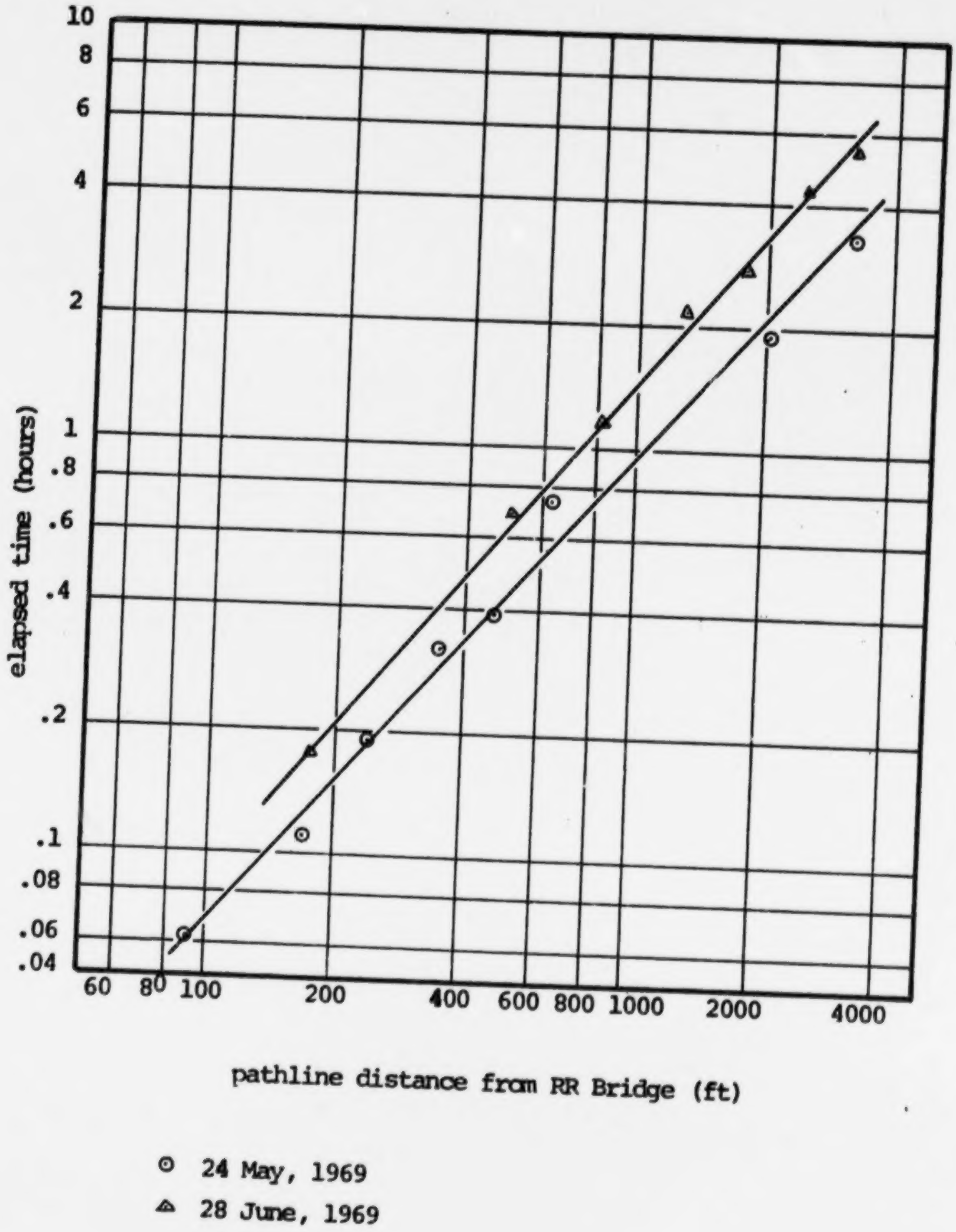


Figure 29. Dye Study Time-of-Travel from Railroad Bridge.

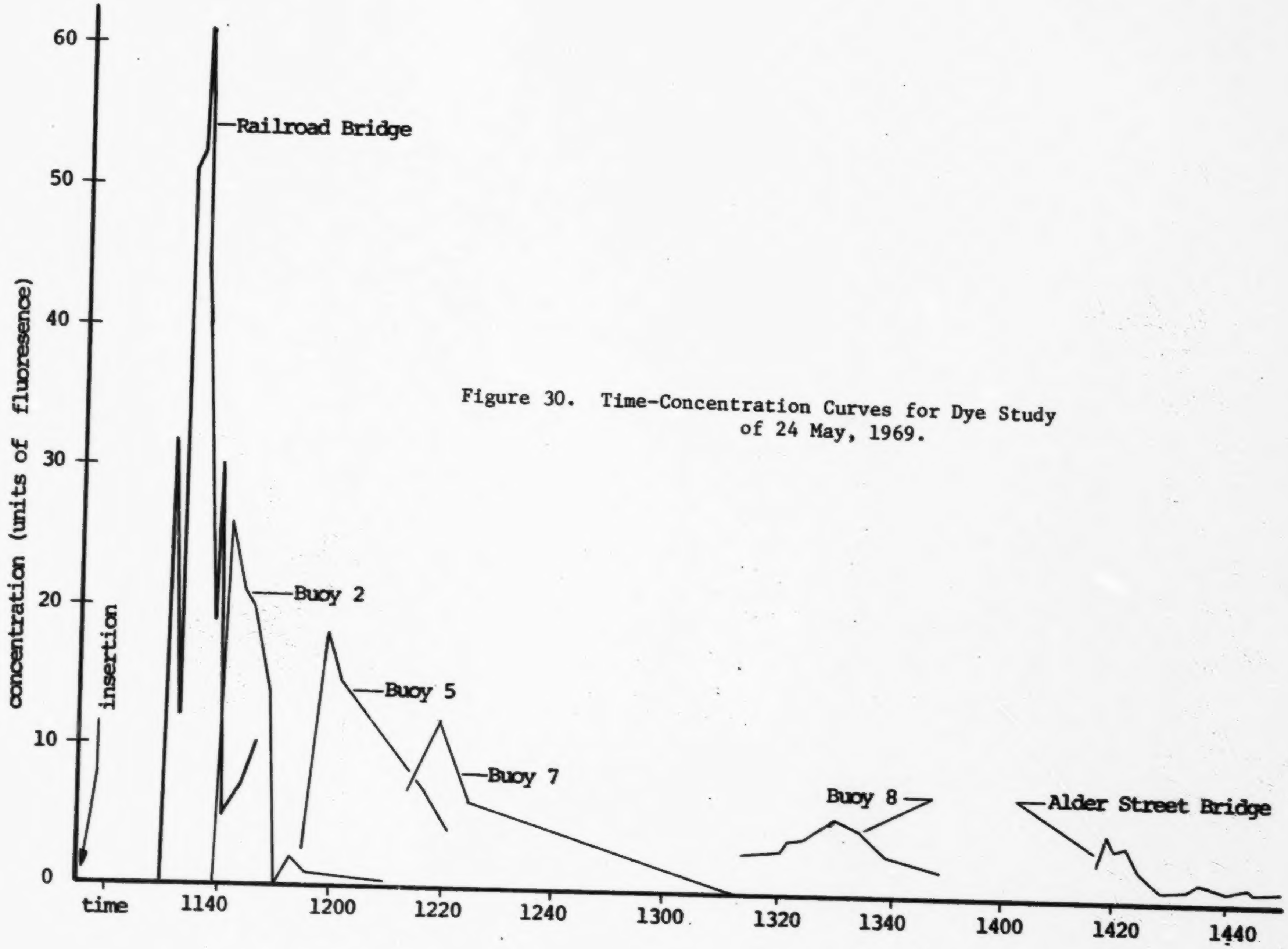


Figure 30. Time-Concentration Curves for Dye Study of 24 May, 1969.

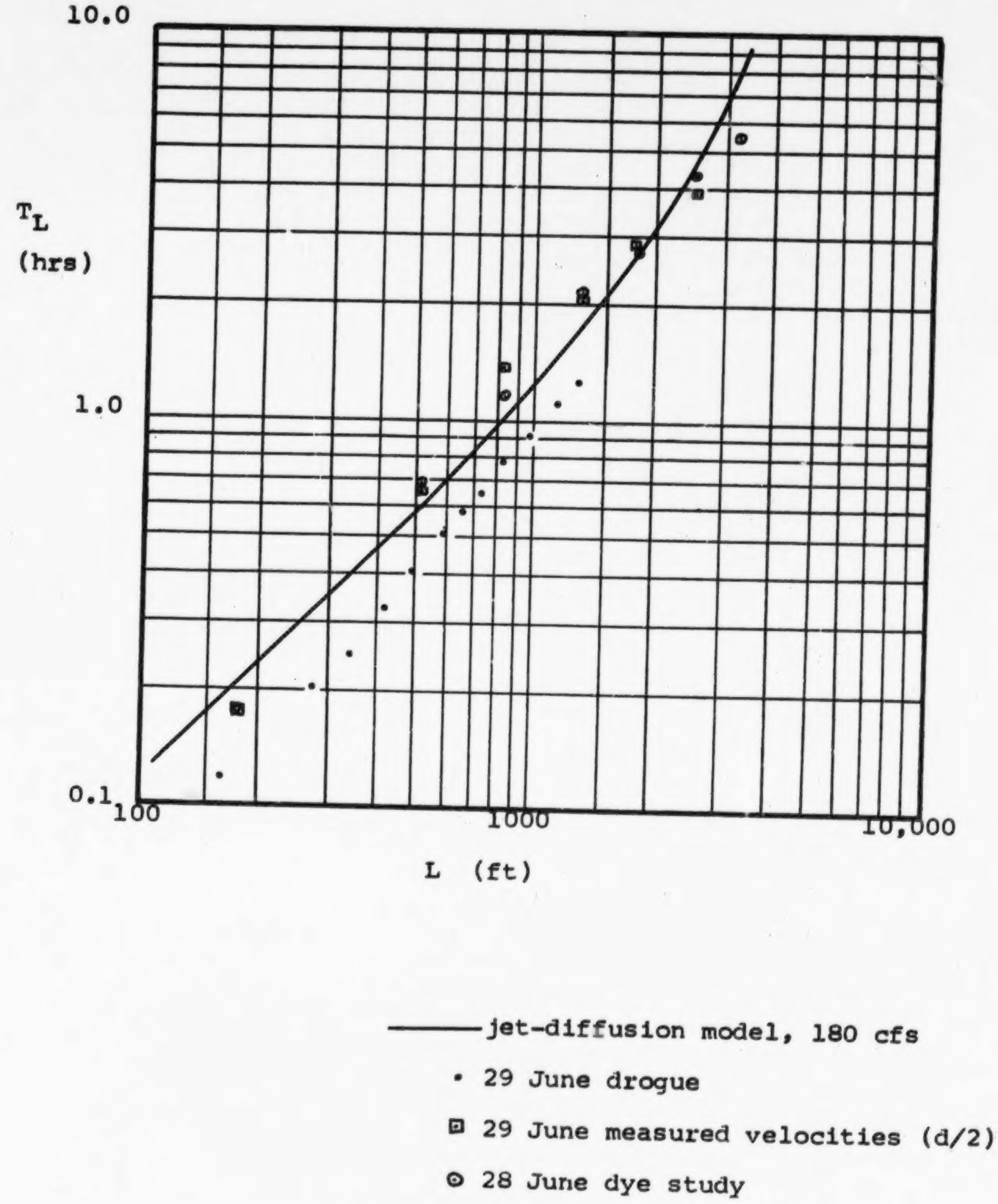


Figure 31. Comparison of 28, 29 June, 1969 Time-of-Travel Data with Jet-Diffusion Model.

$$\text{time} = \frac{\text{Volume}}{\text{Flow Rate}} = \frac{(180 \text{ ac-ft})}{(180 \text{ cfs})\ (2 \text{ ac-ft/day-cfs})}$$

$$= \frac{1}{2} \text{ day} = 12 \text{ hours}$$

Typically, the calculated detention period is several times larger than the through-flow time, a fact verified in both field and laboratory studies. For example, Rumer and Robson (10) report a mean through-flow (or, residence) time of dye tracers of an equivalent prototype value of 434 days in a rotating laboratory model of Lake Erie whereas the ideal detention time was approximately 1000 days depending upon the volumetric throughflow rate used in the calculations. Although their physical scales are grossly different, Lake Erie and the upper basin of Parker Horn have somewhat comparable planforms with well defined inlet and outlet.

The field measurement of the actual flushing time cannot be made. Ideally, this determination would be made by filling the basin with tracer, then allowing inflow to wash out the dye. This procedure would be feasible as part of a laboratory study. (Such a laboratory study on constant-depth lakes of idealized symmetrical elliptical planform has been conducted during 1968-69 at the Albrook Hydraulic Laboratory, Washington State University, but results have not yet been published). The field approach to approximate this technique would be to make a number of single point insertions of dye at various points in the basin, and then to sample concentrations vs. time at these points to observe the decay of tracer concentration to desired levels. This has not been done for the upper basin, and is a step suggested to round out the hydraulic characteristics study summarized in this section. Obviously, the test points must be located in regions outside of the main current patterns, so the number and location of the sampling points must be selected carefully. Some comments on initial attempts to use this technique in lower (main) Parker Horn are given in the next section.

Lower Basin (Main Parker Horn)

The main part of Parker Horn is of more concern to the long-range goals of the Moses Lake study; it has potential recreational uses for exceeding those of the shallow upper basin, and likewise experiences a much greater algal problem. Actual quantitative data and hydraulic observations in the main Parker Horn are very limited, but it is readily observed that the pattern of water movements is much more complex than in the upper basin.

At the site of the shelter housing the water quality monitor recorders, for example, upstream currents exist near the bank and extend some distance offshore. These observations apply to movement of surface waters; upstream surface currents have been observed at this station both with and without winds directed in the northerly (upstream) direction. Velocities are so low that only drogue observations at various depths will provide subsurface velocity data. Movements at night have not been determined, so whether the upstream motion is a consequence of circulations induced by daytime stratified underflows is not known.

During the field studies in the upper basin it was noted that when there was any breeze at all the upper inch or so of water was affected by the wind; when waves formed after sufficient times of wind action it was not possible to make such observations, which apply for relatively smooth water surfaces. It was also observed that while upstream winds could cause counterflow in the top inch or so of water, they have the effect of decreasing downstream - directed water velocities in the upper 0.5-foot or so. Such observations, limited as they are, are in qualitative agreement with other field observations and with laboratory data on water motions (in turbulent flow) set up by blowing air over initially still water bodies.

The conclusion is that wind effects are much greater upon algal mass movements than upon gross water movements. Aerial observations during a dye study of the upper basin on a windy day in 1968 record a surface layer of algae growing upstream from the Alder Street bridge during the day, with the observed upstream penetration being about 500 feet at the end of the afternoon whereas early in the morning there was no surface intrusion of the algae which were blown from the lower basin and through the bridge opening. Distinct surface layers of algae which have formed in the lower basin during the day often have been observed to vanish overnight due to the vertical mixing associated with the diurnal cooling of the lake waters. This suggests that from a hydraulic viewpoint, flushing operations would be most successful at night when algae tend to be more distributed throughout the vertical water column. Also, as stratified flow conditions (which still require further 24-hour temperature profiles to check on their diurnal behavior) should be less pronounced during the nights and early mornings, a single density (unstratified) hydraulic model could well produce initial, meaningful results.

Approximate detention times can be calculated for the main basin of Parker Horn, using inflows which might be feasible for flushing operations. Through-flow times have not been measured. The problem is whether the time-average velocities associated with flushing flows will be more effective in transport of algae and nutrients downstream during the times when these are mixed throughout the water mass than is the upstream transport of algae at the surface due to wind-driven motions of a thin surface layer of water and algae. Through-flow times and associated velocities may be more effective in algal mass transport than the average velocities which would be associated with the detention time calculation. A program of drogue observations will be required for the field observations, because (as mentioned) velocities are too low for the available current meters and accurate dye tracing would be more difficult in the larger basin.

Estimates of complete flushing (action total water replacement) times would be made by the insertion of dye traces at a number of points in the basin. A very limited number of such tests were attempted in August, 1969. Dye was added at three depths at two points in Parker Horn, one at about midway through the horn and another at the "upstream" end during a south wind. At the point midway through the horn, water was moving upstream at all depths tested; 3, 5 and 8 feet. Dye was added there at 12:25 p.m. and had nearly all disappeared in a very short time - about ten minutes. At a point about 2,000 feet upstream the dye was detected at 3 and 5 feet depths at 2:50 p.m. and it was observed to decay very gradually. At another upstream point of some 650 feet farther, dye was again detected at 3 feet at 4:20 p.m. Although dye was detected an estimated 2,000 and 2,650 feet upstream from the addition site some two and four hours later, the surface level was only about 1% of the initial. Thus, there was obviously much lateral dispersion that occurred in that 2,000 feet, which suggests that the net upstream water movement is not appreciable. Nevertheless, the rapid disappearance of the dye following the initial addition along with observations of algal mass movements in the surface film, indicates that there is a mechanism for moving algae, that have a tendency to float during midday warming, upstream toward the head end of Parker Horn during periods of southerly winds.

Dye added to 3 and 5 feet depths at the upstream end of main Parker Horn decayed exponentially at first, but then the concentration leveled off and actually increased about an hour following the time of addition after which it again decreased. Thus, it appeared that water was moving in a circular pattern at the upstream end of the horn during a south wind.

Modeling Algal Productivity and Distribution

One of the goals of this study was to develop a mathematical model for simulating and predicting changes in the water quality and the algal productivity of Moses Lake resulting from a program of flushing and dilution with Columbia Basin Project water. Two classes or types of model were to be investigated; a deterministic model based on mathematical descriptions of the basic mechanisms and processes operative in the lake, and a stochastic model based on statistical evaluation of data describing the behavior of the lake over an extended period of time.

Definition of the hydrodynamic properties of the lake and their influence on its biological behavior were matters of major interest and importance to the proposed system modeling effort. Unexpected cancellation of planned flushing experiments and an ensuing major reduction in field studies and data collection seriously impaired the modeling and simulation aspects of the study. The data and information obtained during the course of this study provide a much better description of phytoplankton productivity and distribution than hitherto available, but they are not adequate for developing a mathematical model for simulating the biological response of the lake to flushing or changes in water quality. Owing to lack of data the stochastic modeling effort had to be abandoned. Development of the deterministic model was restricted to formulation of a generalized conceptual model describing the rate of change of algal biomass distribution throughout the lake. A schematic representation of the model as applied to the Parker-Lewis Horn area of the lake is shown in Figure 32 and the basic model equations and variables are briefly described in the following section.

Proposed Model

Field studies have disclosed that Moses Lake behaves both biologically and hydraulically as though it were divided into a number of regional sections or zones. The proposed model accordingly treats the lake as a string of interacting cells corresponding to the regions identified in Figure 2 and describes the total biomass present in each cell by means of mass balance equations. The quantity of algae present at a specific time and location is considered to be related to the algal growth rate, to the rate at which algae are being permanently removed (death, predation, sedimentation,

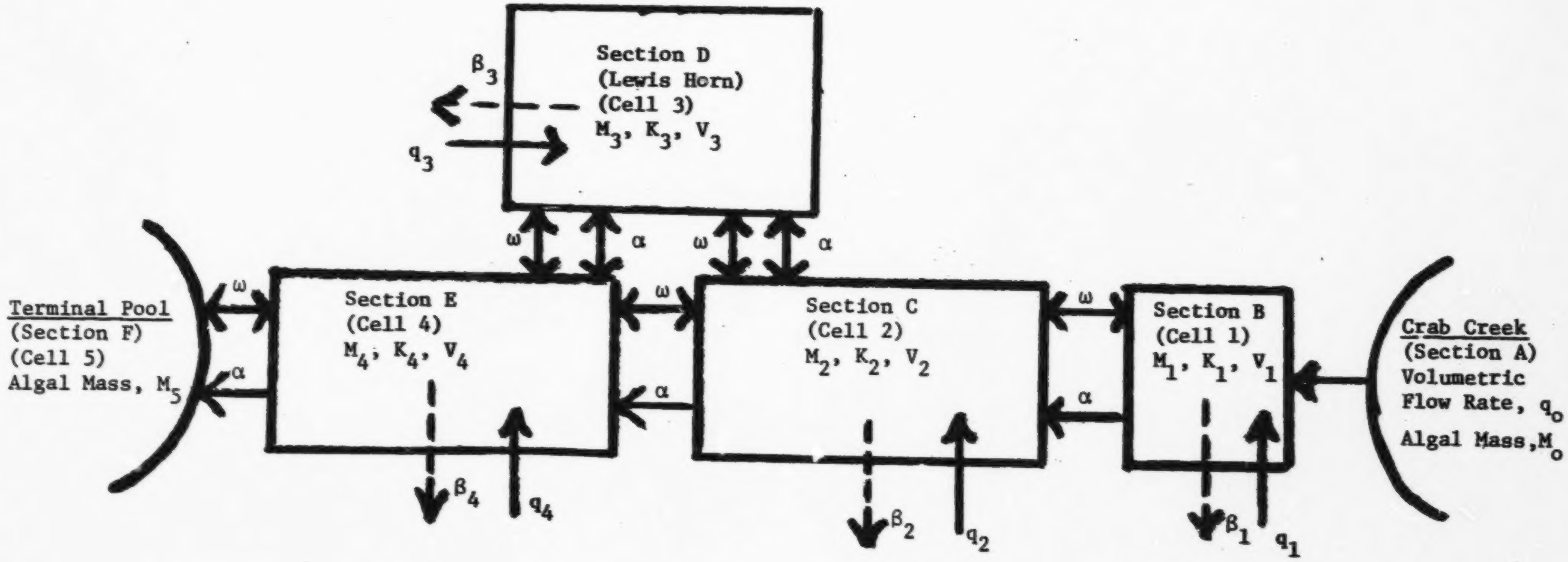

Section D
(Lewis Horn)
(Cell 3)
M_3, K_3, V_3
β_3
q_3
ω
α
ω
α
Terminal Pool
(Section F)
(Cell 5)
Algal Mass, M_5
ω
α
Section E
(Cell 4)
M_4, K_4, V_4
β_4
q_4
ω
α
Section C
(Cell 2)
M_2, K_2, V_2
β_2
q_2
ω
α
Section B
(Cell 1)
M_1, K_1, V_1
β_1
q_1
Crab Creek
(Section A)
Volumetric
Flow Rate, q_o
Algal Mass, M_o

Figure 32. Multicompartment Model of the Parker-Lewis Horn Portion of Moses Lake.

entrapment, etc.) and to the rate at which they are being transported into or out of the location. Some of the difficulties associated with defining and dealing with the above phenomena are briefly discussed below following description of the basic model equations.

Model Equations

The proposed model consists of a set of mass balance equations describing the rate of change in the total amount (mass) of algae in each of the compartments or cells comprising the lake or portion of the lake under consideration. The flow or transfer of algae occurring between adjacent cells is defined by a generalized mass displacement ratio term for wind induced surface currents and a similar term relating to the bulk flow of water through the system. The rate at which the quantity of algae present in any cell in the system is changing at any given time is defined by the following equation:

$$\frac{dM_i}{dt} = K_i\,(M_{l_i} - M_i) + \sum_j \alpha_{ji} M_j + \sum_j \omega_{ji} M_j - \sum_i \alpha_{ik} M_i - \sum_i \omega_{ik} M_i - \beta_i M_i \qquad (1)$$

where M_i is the total mass of algae present in the i^{th} cell at any given time t, M

M_{l_i} is a limiting mass of algae that could be produced or sustained in the i^{th} cell solely by photosynthesis, M

M_j is the total mass of algae present in an adjacent interacting cell, M

K_i is the photosynthetic growth rate of the algae present in the i^{th} cell, T^{-1}

α_{ji} is the hydraulic displacement ratio of the j^{th} cell tributary to the i^{th} cell; a function of the volumetric inflow rate to the cell divided by its volume, T^{-1}

α_{ik} is the hydraulic displacement ratio of the i^{th} cell contributing to the k^{th} cell in the system, T^{-1}

ω_{ji}, ω_{ik} are wind induced displacement ratios, T^{-1}

β_i is the fractional algal loss rate term for the i^{th} cell, T^{-1}

The hydraulic displacement ratio and the detention time of each cell are related to cell volume V_i and to the volumetric flow rate introduced by surface and ground water flows, q_i. As shown in Figure 32 a cell may be linked to more than one adjacent cell and the transference of algae steming from hydraulic displacement or from surface currents may reverse direction. An allocation or assignment matrix therefore is required for each type of displacement function defining origin, destination, and sign.

Evaluation of Model Variables

Each of the variables and terms incorporated in the proposed system model are extremely difficult to measure or describe accurately. The mass term, for example, while seemingly simple and amenable to direct measurement in the field actually requires frequent sampling at several different depths and several different locations in a given cell in order to account for temporal and spatial variations in biomass concentrations caused by stratification and wind induced surface currents and mixing. The required frequency and duration of sampling is related to the nature of the phenomenon of interest; diurnal events and initial response to flushing, etc. would require a sampling frequency on the order of one or two hours over a period of several days for accurate description. The spatial distribution of the sampling network also must account for the influence of wind and currents and the spatial scale of phenomena of special interest such as the flow patterns produced by the introduction of flushing water, etc. In order to adequately define seasonal variations in algal productivity an accurate mass balance would have to be established for each section of the lake on a weekly basis from early spring to late fall. Detailed biomass sampling programs of the type referred to above have not been attempted at Moses Lake and the data and information available provide only a very rough approximation of seasonal variations in the biomass in a few segments of the lake.

The algal growth rate term, K, employed in the model equations is considered to be a function of species and environment (nutrients, temperature, available light, etc.). As a consequence K may be expected to exhibit spatial as well as diurnal and long term variations. The significance of these variations is related to the time scale employed in the stimulation and tends to diminish in importance as the time unit increases (say from hours to days to weeks, etc.). Sufficient data and information are not available for making accurate or reliable instantaneous growth rate predictions. It therefore will be necessary to work with generalized time averaged estimates of K obtained from *in situ* growth studies or deduced from experimental studies employing the system model.

The rate at which algae are lost from the system likewise cannot be measured or predicted with any certainty. The loss rate, however, may be estimated from field observations or possibly from the system model if the other variables and parameters are defined.

The distribution and concentration of algae observed throughout the lake is influenced to a large extent by the general flow or movement of water through the lake and by wind induced surface currents. Surface currents have been observed to transport large quantities of algae toward the upper end of Parker Horn. Hydraulic displacement causes a general movement of algae toward the outlet from Moses Lake and determines detention times throughout the lake. The onset of algal blooms and the amount of algae present in the extremeties of the lake appear to be related to detention time. The transport of algae between various segments of the lake is accounted for in the model by the hydraulic and by the wind induced displacement ratios referred to earlier. Quantitative definition of these parameters is yet to be established and the problems associated with their measurement are discussed in those sections of the report dealing with the hydraulic field studies and the hydraulic modeling aspects of the study. The wind induced displacement ratio of each cell might be estimated from surface float studies and the hydraulic displacement ratios should be related to cell volumes and their longitudinal length, geometry and volumetric flow rates.

DISCUSSION

Biological

The cluster analysis of the plankton species and sample data collected during this study have clearly shown that very subtle qualitative differences in the biota from one region of a lake to another are readily detectable. Similarly, aspects of community structure which would otherwise go unnoticed are called to one's attention by cluster analysis. The background data on community types and their distribution should provide an excellent base from which to judge future changes in water quality and/or land use practices in and around Moses Lake.

Some marked patterns were noted in the few physico-chemical measurements associated with the sample groups. However, the data available were not sufficient to develop definite relationships. The probability of discovering what environmental factors control biological variation in a particular case seems small when both (1) the measurements to be made and (2) the organisms whose response is to be correlated with the measurements, are chosen at random. The cluster analysis approach, which would first determine something about community structure, and identify groups that are apt to respond uniformily to environmental changes, should improve the chances of finding meaningful cause and effect relationships.

Cluster analysis may also be useful in selecting organisms or organism assemblages for bioassay experiments. By ascertaining objectively which organisms tend to occur together, or which organisms are characteristic of different community types, rational decisions can be made in selecting species representing a broad spectrum of environmental requirements. This will help eliminate the need to test every species before coming to a generalized conclusion regarding the effects of a specific agent upon a natural community.

One of the areas in the lake shown by cluster analysis to have a consistently and distinctly different algal community from that of the main body of the lake is the northern most end of Pelican Horn (K). The qualitative similarity between transects J and K are attributable to the flow of water from K into J. The abundance of different species in J and K is markedly different, resulting in an obvious color difference, while the total biomass (as measured by total seston, combustible seston, chlorophyll _a_, or particulate carbon) in the two segments is not very different during summer months. The nutrient conditions differ considerably between J and K (since the sewage plant discharges into J), the mean residence time of water is certain to be much less for K than for J, and the mean depth of K is somewhat less than for J. This is an interesting aspect of the background data developed by cluster analysis and would require considerably more intensive study to identify the causes.

Communities of algae present over most of the lake during mid- and late summer when unsightly conditions occur is to a high degree made up of species of group 7 (Figure 6 and Table IV). This group includes the blue green algae _Anabaena circinalis_, _Aphanizonenon holsaticum_, _Coelosphaerium naeglianum_ and _Microcystis aeruginosa_. These four species showed some of the highest occurrence frequencies in the samples examined. In particular _Aphanizonenon_ and _Microcystis_ are the nuisance causers because of the hugh biomasses that they form. Although these species and others in their group (7) occur in samples collected in the spring (sample groups 3 and 6 are most prevalent) their correspondence to and frequency in these groups are only moderate. The diatoms such as Fragilaria and Nitzschia occur most frequently in spring. Thus, there is a seasonal succession in community types and in the case of the nuisance species, which are present early in the growing season even though more infrequent, there seems to be a gradual merging to a point during mid-summer when they are most frequent in occurrence.

Although data are not sufficiently complete at this time to determine relationships between algal biomass and environmental factors, the likely importance of certain factors is indicated. The effect of detention time on algal growth and community types is probably important both in the spring and in the fall. The isolation of Pelican Horn with respect to surface inflow streams and observations of turbidity in the spring suggest that it may be one of the last areas reached by inflow water. Two biological observations relate to this. During the fall Pelican Horn is the last area for occurrence of algal sample groups that had been prevalent all over the lake in summer. Sample groups in which occurrence of nuisance blue green algal is frequent. In the spring, sample groups that are first prevalent in Pelican Horn are eventually prevalent elsewhere in the lake as the season progresses. Further, maximum algal biomass occurs earlier in Pelican than Parker Horn. Greater detention time of water in Pelican Horn would allow faster biomass accumulation there because cells would not be lost as fast by washout and the initial inoculum would be greater at any given time when environmental conditions became favorable. Also, the presumed slower water exchange would tend to allow the slower growing species to persist there.

Of the environmental factors measured, only light and possibly nitrate content would likely have a limiting effect on the summer algal mass and here again the data are not sufficient to point out significant relationships. Simply from the basis of quantities of phosphorus available, growth limitation from this nutrient seems unlikely. Nitrate, on the other hand, is in shorter supply and does decrease to near zero at times in downstream sections of the lake. The relatively shallow photic zone which is at times less than 1 meter, and the surface collecting habits of the blue green algae, suggest that light limitation through self shading is also likely.

A factor that would seem highly significant in determining algal growth and species composition is mixing depth. Parts of the lake stratify during the day and depending on the degree of surface cooling, stratification can break up in the evening or at night and vertical mixing will increase. Such frequent mixing throughout the summer may deliver sufficient regenerated nutrients to the surface water to continually promote blooms of the nuisance blue green algae. Some indication of this is given by phosphorus, chlorophyll a and temperature gradient data. Plans are to further study the effect of mixing by measuring the relative fertility of surface waters by algal bioassay before and after periods of mixing.

The limited data presently available from the in situ plankton experiments indicate that algal growth is reduced by adding dilution water relatively low in nutrients. However, considering that dilution water contained total phosphate at only about 6% that of lake water, measured phosphate levels in the 90 and 86% lake water dilutions were not consistently less than those in the control. From the lack of consistent differences between control and test containers it is difficult to infer that the measured effect on plankton growth is due to less phosphorus. The effect of diluting the algal mass in lake water on the growth response was partly controlled for by adding filtered lake water (100 μ mesh size net) to unfiltered lake water (54%). Almost without exception chlorophyll a content in this test container was greater than in containers with low-nutrient dilution water. It seems fair to conclude that the reduced growth that is observed is due to the lower nutrients in dilution water. Whether nitrate content explains this difference better than phosphorus must await complete compilation of the data.

The objective of the other pair of experiments was to determine if "conditioning" or "aging" of the water is necessary to stimulate growth of nuisance algal species and if stimulation is increased by greater detention times of water. Such conditioning may result from a build up of dissolved organic products excreted from algal populations within the lake that favor the nuisance forms either as growth stimulators or inhibitors to competing species (11, 12). This effect of increased detention time may be an additional one to the two usually considered, that is, reduced losses of cells and nutrients from the system. The greatest response in filtered (0.5-1.0 μ pore size) test water was from the upstream-most point in the lake proper. Growth response was poorest in the stream inflow water and this difference is not attributable to phosphorus content. Whether this "conditioning" factor is real will require careful evaluation of results from these two experiments. This evaluation may show need for additional experiments during the coming growing season with an altered design.

Direct observation of surface water movement, diurnal measurement of plankton abundance and production, and limited study of circulation patterns indicate that a large portion of the algal biomass measured in Parker Horn does not originate there. The nuisance algae are buoyant so recruitment into the surface water from the entire water column is possible during warm, calm periods. Southerly winds, which are common during summer, visibly transport the algae, floating near the surface, northward, where they accumulate against the Alder Street causeway. That this is what happens is strongly indicated by the diurnal production--chlorophyll a data collected at a point in mid Parker Horn. Here chlorophyll a in the total water column built up to a level in the evening about six times that measured during the morning. This increase was about 25 times greater than could be accounted for by net photosynthesis. Collaborating evidence from limited dye-decay studies indicates that fairly rapid upstream movement of water, particularly near the surface, does occur. Also this upstream movement appears to include more than just the surface film.

Before instigating a flushing program, if such becomes feasible in the future, a detailed description of current patterns in Parker Horn and also in the main part of the lake would be necessary. Although recognized early as an important aspect of this study curtailment of funding after the first year greatly restricted the project scope. Further the diurnal patterns of chlorophyll a and temperature profiles indicate that flushing may be more effective at night when the algae are more evenly distributed. During the day, flushing water inflow may simply enter Parker Horn and flow along the bottom and have little effect on the upstream transport of algal mass near the surface. A possible solution to this upstream transport problem might be a series of floating surface skimness which check the northward drift of a large portion of algae or a series of causeways with navigational openings to further sectionalize the lake. Such a structure should tend to increase the effectiveness of a given amount of flushing water in removing algae and preventing their return into Parker Horn.

Hydraulic - Model Feasibility

Moses Lake, and in particular those parts which would be considered in a physical hydraulic model (Parker Horn, the lower main lake, and perhaps Pelican Horn) is a shallow lake in which the driving forces causing water movements are gravity, winds, and effects of thermal stratification. All of these factors must be considered in designing the hydraulic model.

A further concern in the modeling of a lake in which water current velocities are low is whether or not Coriolis effects must be considered. An investigation of the relative magnitude of the various driving forces is given below, making use of observed hydraulic characteristics of Moses Lake; the analysis is comparable to that of Harleman et al. (13).

The following data by Holly (7) are used in the evaluation of the gravitational forces, and use velocity measurements of 25 May 1969, at locations indicated on Figure 25. The inflow to the upper basin was 150 cfs, mean depth y was 5 feet.

Station	Point	u_{typ}, fps (representative velocity)	u_*, fps (from log. plotting)
9	1	0.27	0.038
8.5	2	0.10	0.01

Utilizing the equivalent open channel approximation,

$$\sqrt{T_o/P} = u_* + \sqrt{gyS} \tag{E}$$

where S = the equivalent slope for uniform flow

g = gravitational acceleration,

yields the respective values of $S - 9.0 \times 10^{-6}$ and 6.4×10^{-7}. The components of the gravitational acceleration directed parallel to the equivalent surface slope are 29×10^{-5} and 2.0×10^{-5} feet per second per second, respectively.

Equivalent Coriolis accelerations are calculated by

$$a_c = 2\Omega u_{typ} \sin \phi \tag{F}$$

Where $\Omega = 0.73 \times 10^{-4}$ radians per second, the earth's rotational velocity

ϕ = latitude (= 47°08' for the upper basin)

The corresponding Coriolis accelerations computed by Eq. (F) are 2.7×10^{-5} and 1.0×10^{-5} fpsps, respectively, for the tabulated water velocities. Coriolis accelerations are smaller than gravitational components. Further, the above results are for a low flow (Q = 150 cfs), and the flushing flows would be much larger. Assuming similarity of velocity profiles at the higher inflow rates, $S \propto u_* \propto u^2$, so gravitational forces will increase in proportional to Q^2; Coriolis accelerations, on the other hand, vary linearly with current speed and therefore would increase in proportion to Q. It therefore seems safe to neglect Coriolis effects, and a stationary, larger scale hydraulic model can be used in place of a more complex, although smaller, rotating model.

First order approximations of the relative significance of wind effects may be made by utilizing the Ekman equation (strictly valid for deep, homogenus waters in which the motions are wind - induced).

$$V_o = \frac{T_a}{\sqrt{2A\rho\Omega \sin\phi}} \qquad (G)$$

where V_o = water-surface current velocity induced by wind

T_a = shear stress on the water surface due to wind

A = eddy viscosity.

Using V_o = 0.25 feet per second (perhaps a maximum value, based on visual but not measured field observations) and a value of A = 0.4 pound-second/foot squared, the corresponding value of T_a is 0.0023 pounds per square foot. (The value of A corresponds to a kinematic eddy viscosity of 200 sq. cm per sec, a value quoted by Liggett and Hadjitheodorou (14) as appropriate to currents in the Great Lakes and used by them in a mathematical model of motions in a shallow lake). The bottom shear stress, corresponding to $u_* = 0.038$ fps, to $T_o = 0.0028$ psf. Wind stresses at the surface therefore seem to be of the same order of magnitude as bottom shear stresses due to gravity flow, at least for low inflows to the basin, so that wind effects should be considered in the physical model. Wind effects can be reproduced in the model only after trial verification procedures. Such verification would apply to simulated surface layers of algae only, however. From the hydraulic viewpoint, and based on comments in the results section, it is considered that wind effects have a secondary influence on water movements and mixing processes in Moses Lake.

Consideration of requirements of modeling stratification effects due to diurnal temperature variations will be deferred until after some comments on model scale.

The section of Moses Lake to be modeled has an approximate length of 6 miles. Selecting a reasonable laboratory distance of about 30 feet to represent the prototype distance, the horizontal scale ratio for the model would be $L_r = 1:1,000$. The model would require vertical distortion to insure turbulent flows throughout. If a minimum model depth of 3 inches = 0.25 foot is selected to simulate conditions in the 5-foot deep upper basin, the corresponding vertical scale ratio is $y_r = 1:20$. For such a scale ratio, the greatest model depths would be about 18 inches, in the area of the Moses Lake outlet. (The model should incorporate all of Parker Horn, and the lower main lake including the outlet, as well as Pelican Horn). The velocity and time scales become

$$V_r = (y_r)^{1/2} = (1:20)^{1/2} = 1:4.47$$

$$t_r = L_r/V_r = (L_r)/(y_r)^{1/2} = 1:224$$

The model time simulating one prototype day therefore is 6.5 minutes. If density inflows are to be simulated, then densimetric Froude number similarity for the above distorted Froude law model requires the same density differential between surface waters and inflowing water in the model as in the field. The maximum temperature differences which have been observed between top and bottom elevations in Parker Horn (lower basin) and in the lower main lake indicate that density differentials would be no greater than about 0.1 percent. The feasibility of varying the density of the inflow over a range of 0.1 percent and in a 6.5 minute period (accepting for now the preliminary suggestion of scale ratios) by cycling flows from batches of saline solution has not been investigated. Such a procedure is possible, and would require far less model experimentation than would an attempt to model solar heating effects by means of heat lamps distributed over the surface of the stationary model.

The preliminary conclusion is that gross water movements could indeed be simulated in a distorted Froude law model. Initial model verification would be done in the absence of wind. Trial arrangements of blowers next would be done in the absence of wind. Trial arrangements of blowers next would be made to simulate wind effects, with attention limited to the water surface. Density simulation would be a final step, although it has not been demonstrated yet how significant the thermal effects are upon water movements. The amount of attention to be devoted to wind and density-differential effects in an hydraulic model must depend upon the relative significance of that amount of algae which remains on the water surface during the day to the total biological population of the water mass.

SUMMARY AND CONCLUSIONS

1. **Cluster analysis of plankton data identified six sample groups and seven species groups. Each of these groups exhibited unique temporal and spatial distribution patterns.**

2. Temporal and spatial variations in community types and standing crops in Moses Lake appear to be related to detention time, nitrate content, and available light. These relationships may resolve better when a larger and continuous group of data are available for analysis.

3. In situ studies of the effect of low-nutrient dilution water on lake plankton growth response indicated reduced growth at 90% and 86% lake water. Other preliminary results show somewhat better growth in filtered lake water than in filtered inflow water from Crab Creek. These results cannot be attributed to phosphorus, since levels were high and variable in most test containers and showed no pattern related to growth.

4. Diurnal water quality data collection and analysis illustrated certain uses for monitor data in addition to basic information - namely a record of surface to bottom mixing. Wind induced mixing greatly interfered with attempts to determine algal productivity from diurnal variations in oxygen. Positive relationships were found between algal pigment concentration and the sub-photic zone respiration rate, however.

5. General agreement was obtained among three field techniques for determining time-of-travel through a section of upper Parker Horn. These estimates for through-flow of peak due concentrations were 5.4 and 2.8 hours for 150 and 180 cfs inflow, respectively. Computed flushing time, or complete replacement of the volume, was 12 hours at 180 cfs. Field verification was not attempted but a procedure for same is suggested.

6. Dye studies, diurnal plankton sampling and field observations indicate that southerly winds have a great effect on moving algae upstream into upper Parker Horn. The effect of wind on algal movement seems to be greater than on water movement. Many times more algae are apparently transported into Parker Horn than grow there.

7. A preliminary conclusion is that water movements in the lake could be simulated in a distorted Froude law hydraulic model. The emphasis placed on wind and density - differential effects will depend on the proportion of the algal crop that occurs near the water surface.

8. Based on algal buoyancy and wind transport complications during the day along with nighttime cooling and greater mixing, removal of algal and nutrients by flushing procedures in Parker Horn and the lower lake would likely be more effective at night. The removal of algae from Parker Horn by means of flushing apparently may be overcome or reversed during the day by wind action.

9. Field studies have disclosed that the lake behaves both biologically and hydraulically as though it were divided into several partially isolated regions.

10. A tentative mathematical model has been set up for simulating the productivity and distribution of algae throughout the lake. The model treats the lake as branching strings of interacting compartments or cells corresponding to the various lake regions identified through field studies. Verification and application of the model must await more complete and accurate description of phytoplankton concentrations throughout the lake and the mixing, stratification and fluid circulation that occurs.

11. Flushing Parker Horn, with large slugs of low nutrient water, as the only measure to control algal growth, may not be as effective as originally thought. Because of wind action transporting algae and their entrained nutrients back into the Horn together with nutrient regeneration from sediments, a negative effect on algal production may be short lived.

12. Control programs that may be expected to have more lasting effects might include continuous addition of rather small quantities of low-nutrient water into Parker Horn coupled with a reduction of the nutrient inputs from Rocky Ford Creek (approximately 1/3 of the phosphorus supplied to the lake) and the sewage treatment plant effluent (approximately 1/3 of the phosphorus input). Also, drainage of the lake from the upper end of the two Horns would take advantage of wind transporting action on the algae and be more effective in algal removal than would flushing water that might tend to underflow the surface water and accentuate the algal transport by the wind.

13. Development of background data describing plankton community changes in the lake and relating these to environmental factors by observation and experiment will continue in the lake through 1971. Such information should provide a valuable reference point and basis for hypothyses related to future experimental measures to control algal growth.

LITERATURE CITED

1. Oglesby, R. T., "Effects of controlled nutrient dilution on eutrophication of a lake." International symposium on Eutrophication, Madison, Wisconsin, June 11-16, 1967. (In press)

2. Oglesby, R. T., "Dilution effects on nutrients and primary productivity." Department of Civil Engineering, University of Washington, 1968, 40 pages.

3. Sylvester, R. O. and R. T. Oglesby, "The Moses Lake Water Environment." University of Washington, Department of Civil Engineering, 89 pages, 1964.

4. Nunnallee, D. A., "Engineering aspects of nuisance algal control in Moses Lake." M.S. thesis in Civil Engineering, University of Washington, 126 pages, 1968.

5. Strickland, J. D. H. and T. R. Parsons, "A practical handbook of seawater analysis." Fisheries Research Board, Canada, Bulletin 167, 1968.

6. American Public Health Association, "Standard methods for the examination of water and waste water"(12 ed.), New York, American Public Health Association, Inc., 1965.

7. Holly, Forrest M., Jr., "A field study of dispersion in a shallow lake." M.S. thesis, University of Washington, 1969. (Unpublished)

8. Albertson, M. L., Y. B. Dai, R. A. Jensen and H. Rouse, "Diffusion of submerged jets." Trans. ASCE, Vol. 116, 1951.

9. Fischer, H. B., "Longitudinal dispersion in laboratory and natural streams." Report No. KH-R-12, California Institute of Technology, 1966.

10. Rumer, R. R. and L. Robson, "Circulation studies in a rotating model of Lake Erie." Proceedings of the Eleventh Conference on Great Lakes Research, Milwaukee, Wisconsin, April, 1968.

11. Wetzel, R. G., "Dissolved organic matter and phytoplanktonic productivity in Marl Lakes." Mitt. Internat. Verein. Limnol., Vol. 14, p. 261-270, 1968.

12. Vance, B. D., "Composition and succession of Cyanophycean water blooms," J. Phycol., Vol. I, 81-86, 1965.

13. Harleman, D. R. F., E. R. Holley, J. A. Hoopes and R. R. Rumer, "The feasibility of a dynamic model of Lake Michigan." Publication No. 9, Great Lakes Research Division, Institute of Science and Technology, The University of Michigan, 1962.

14. Liggett, J. A. and C. Hadjitheodorou, "Circulation in shallow homogeneous lakes." Proceedings ASCE, Vol. 95, No. HY2, March, 1969.

APPENDIX A

FORTRAN IV PROGRAM LISTINGS

```
C     ********************************************************************
C     *                                                                    *
C     * THIS PROGRAM READS THE SAMPLE CARDS, SETS UP A SAMPLE VS. TAXON   *
C     * OCCURRENCE ARRAY, AND LISTS THE TAXA WHICH OCCURRED IN EACH SAMPLE *
C     * AND/OR THE SAMPLES WHICH CONTAINED EACH TAXON, DEPENDING ON THE    *
C     * VALUE OF THE VARIABLE 'PROCES'. WHEN PROCES = 1, ONLY TAXA IN SAM- *
C     * PLES ARE LISTED, WHEN PROCES = 2, ONLY SAMPLES CONTAINING TAXA ARE *
C     * LISTED, WHEN PROCES = 3, BOTH ARE LISTED.                          *
C     *                                                                    *
C     * SAMPLE DATA CARDS ARE READ IN I1 FORMAT.                           *
C     *                                                                    *
C     * THE PROGRAM CAN ACCOMODATE 150 SAMPLES AND 150 TAXA.               *
C     *                                                                    *
C     *                                     = = R. J. BUCHANAN             *
C     *                                                                    *
C     ******************************************************************** *
      DIMENSION FMT(84),SAMPLE(150,150),TAXNAM(150,4),SAMNAM(150,4),TITL**
     1E1(12),TITLE2(12)
      INTEGER  PROCES, SAMPLE
      DATA ((SAMPLE(I,J),I=1,150),J=1,150)/22500*0/
C-----READ TITLES, NUMBER OF SAMPLES, NUMBER OF TAXA, FORMAT DECK, TAXON
C-----OCCURRENCE DECK, TAXON NAME DECK, AND SAMPLE NAME DECK.
      READ (5,10) TITLE1
      READ (5,10) TITLE2
   10 FORMAT (12A6)
      READ (5,20) NSAMPL, NTAXA,PROCES
   20 FORMAT (3I5)
      READ (5,10) FMT
      READ (5,FMT) ((SAMPLE(I,J),I=1,NTAXA),J=1,NSAMPL)
      READ (5,30) ((TAXNAM(I,J),J=1,4),I=1,NTAXA)
   30 FORMAT (4A6)
      READ (5,30) ((SAMNAM(I,J),J=1,4),I=1,NSAMPL)
C-----WRITE OUT THE NAMES OF ALL TAXA FOUND IN EACH SAMPLE.
      IF(PROCES.EQ.2)GO TO 95
      DO 90 NS=1,NSAMPL
      NL=0
      WRITE (6,40) TITLE1
   40 FORMAT (1H1,30X,12A6)
      WRITE (6,50) (SAMNAM(NS,L),L=1,4)
   50 FORMAT (1H0,10X,7HSAMPLE=,1X,4A6,1X,14HABUNDANCE CODE,//)
      DO 90 NT=1,NTAXA
      IF(SAMPLE(NT,NS).GE.1)NL=NL+1
      IF(NL.LT.51)GO TO 70
      WRITE (6,40) TITLE1
      WRITE (6,60)
   60 FORMAT (1H0,10X,34H(CONTINUATION OF THE SAMPLE ABOVE)/)
      NL=0
   70 IF(SAMPLE(NT,NS).GE.1   )WRITE (6,80) (TAXNAM(NT,L),L=1,4),SAMPLE
     1(NT,NS)
   80 FORMAT (1H ,10X,4A6,14X,I2)
   90 CONTINUE
C-----WRITE OUT THE NAMES OF ALL SAMPLES CONTAINING EACH TAXON
   95 IF(PROCES.EQ.1)GO TO 135
      DO 130 NT=1,NTAXA
      NL=0
```

```
        LISTNG      -  EFN   SOURCE STATEMENT  -  IFN(S)  -           DATE 07/28/69
      WRITE (6,40) TITLE2
      WRITE (6,100) (TAXNAM(NT,L),L=1,4)
  100 FORMAT (1H0,10X,6HTAXON=,1X,4A6,1X,14HABUNDANCE CODE,//)
      DO 130 NS=1,NSAMPL
      IF(SAMPLE(NT,NS).GE.1  )NL=NL+1
      IF(NL.LT.51)GO TO 120
      WRITE (6,40) TITLE2
      WRITE (6,110)
  110 FORMAT (1H0,10X,33H(CONTINUATION OF THE TAXON ABOVE)/)
      NL=0
  120 IF(SAMPLE(NT,NS).GE.1)WRITE(6,80)(SAMNAM(NS,L),L=1,4),SAMPLE
     1(NT,NS)
  130 CONTINUE
  135 STOP
      END
```

```
$JOB            AB,10,7000         3GA81DO BUCHANAN, R. J.
$ID
$SETUP 9        TAPE
$SETUP 10       TAPE
$EXECUTE        IBJOB
$IBFTC FCTEST   ALTIO
$IBFTC FCTEST
C   ************************************************************************
C   *
    ****************************************************************************
C   * THIS PROGRAM COMPUTES THE FAGER (1963) COEFFICIENT OF SIMILARITY,        *
C   * DEFINED AS C/SQRT(A*B)-1/(2*SQRT(B)), WHERE (A) IS THE FREQUENCY OF     *
C   * OCCURRENCE OF TAXON A OR IS THE NUMBER OF TAXA IN SAMPLE A, (B) IS      *
C   * THE FREQUENCY OF OCCURRENCE OF TAXON B OR IS THE NUMBER OF TAXA IN      *
C   * SAMPLE B, (C) IS THE FREQUENCY OF THE JOINT OCCURRENCE OF BOTH          *
C   * TAXA A AND B OR IS THE NUMBER OF TAXA SAMPLES A AND B HAVE IN           *
C   * COMMON, AND (B).GE.(A).          THIS COEFFICIENT (CALLED (FC) AND      *
C   * MULTIPLIED BY 100 FOR CONVENIENCE) IS COMPUTED FIRST TO EVALUATE        *
C   * THE SIMILARITY OF ALL PAIRS OF TAXA ON THE BASIS OF THEIR JOINT         *
C   * OCCURRENCE, AND THEN A SECOND TIME TO EVALUATE THE SIMILARITY OF        *
C   * ALL PAIRS OF SAMPLES ON THE BASIS OF THE TAXA THEY HAVE IN COMMON.      *
C   *                                                                         *
C   * THIS PROGRAM CAN ACCOMMODATE UP TO 88 SAMPLES, TREATING THEM WITH       *
C   * REGARD TO UP TO 90 TAXA.                                                *
C   *                                                                         *
C   * THE UNCLUSTERED MATRICES OF FC ARE WRITTEN ONTO BINARY SCRATCH          *
C   * TAPES FOR INPUT INTO THE CLUSTER PROGRAM, -CLUSTR-, AND THEN THEY       *
C   * ARE CONVERTED TO FCX100 FOR PRINT-OUT.                                  *
C   *                                                                         *
C   * THE FINAL PRINT-OUT DISPLAYS THE FC VALUES IN THE UPPER RIGHT HALF      *
C   * OF THE MATRIX, THE C VALUES IN THE LOWER LEFT HALF OF THE MATRIX,       *
C   * AND THE TAXON NAME WITH ITS FREQUENCY OF OCCURRENCE (OR THE SAMPLE      *
C   * NAME WITH THE NUMBER OF TAXA IN THE SAMPLE) DOWN THE LEFT SIDE OF       *
C   * THE MATRIX.  DUPLICATE PRINT-OUTS ARE MADE.                             *
C   *                                                                         *
C   *                          -  IMPORTANT NOTICE ---                        *
C   * WHEN PROCES=1.0, FC IS COMPUTED FOR TAXA ONLY.  WHEN PROCES=2.0,        *
C   * FC IS COMPUTED FOR SAMPLES ONLY.  WHEN PROCES=3.0, FC IS COMPUTED       *
C   * FOR BOTH TAXA AND SAMPLES.  THIS APPLIES ALSO TO THE WRITING OF         *
C   * TAPES FOR THE CLUSTER PROGRAM.                                          *
C   *                                                                         *
C   * SAMPLE DATA CARDS ARE READ IN F1.0 FORMAT.                              *
C   *                                                                         *
C   *                                             == R. J. BUCHANAN           *
C   ************************************************************************  *
                                                                              *
      DIMENSION FMT(84 ),SAMPLE(90,88),FCX100(90,90),TAXNAM(90,4),SAMNAM*******
     1(88,4),TITLE(12),FTAXON(90),CC(90,90),FSAMPL(88) ,FC(90,90)
      INTEGER LIMIT1,LIMIT2,      FCX100,CC,FTAXON,FSAMPL
      EQUIVALENCE (FCX100(1,1),FC(1,1))
      DATA A,B,C/3*0.0/,((FC(I,J),I=1,90),J=1,90)/8100*0.0/,(FTAXON(I)
     1,I=1,90)/90*0/,(FSAMPL(I),I=1,88)/88*0/,((SAMPLE(I,J),I=1,90),J=1,
     288)/7920*0.0/
C-----READ TITLE, NUMBER OF SAMPLES, NUMBER OF TAXA,TYPOUT,AMOM,PROCES.
C     READ FORMAT DECK, TAXON OCCURRENCE DECK, TAXON NAME DECK, AND
C     SAMPLE NAME DECK.
      READ(5,10)TITLE
   10 FORMAT (12A6)
```

```
      READ(5,20)NSAMPL,NTAXA,TYPOUT,AMOM,PROCES
   20 FORMAT(2I5,3F5.1)
      READ(5,10)FMT
      READ(5,FMT)(SAMPLE(I,J),I=1,NTAXA),J=1,NSAMPL)
      READ(5,30)((TAXNAM(I,J),J=1,4),I=1,NTAXA)
   30 FORMAT(4A6)
      READ(5,30)((SAMNAM(I,J),J=1,4),I=1,NSAMPL)
C---- COMPUTE FAGER COEFFICIENT, -FC-, FOR ALL PAIRS OF TAXA OR SAMPLES.
      DO 350 NL=1,2
      IF((PROCES.EQ.2.0).AND.(NL.EQ.1))GO TO 350
      IF(PROCES.EQ.2.0)GO TO 121
      IF(NL.EQ.1)GO TO 125
      DO 120 JJ=1,NSAMPL
      DO 120 KK=1,NSAMPL
      FC(JJ,KK)=0.0
  120 CC(JJ,KK)=0
  121 LIMIT2=NSAMPL
      LIMIT1=NTAXA
      GO TO 210
  125 LIMIT2=NTAXA
      LIMIT1=NSAMPL
  210 LMT2M1=LIMIT2-1
      DO 215 JJ=1,90
      FC(JJ,JJ)=-100.0
  215 CC(JJ,JJ)=-100
      DO 60 I=1,LMT2M1
      IP1=I+1
      DO 60 J=IP1,LIMIT2
      DO 50 K=1,LIMIT1
      IF(NL.EQ.1)GO TO 230
      IF(SAMPLE(K,I).GE.2.0)A=A+1.0
      IF(SAMPLE(K,J).GE.2.0)B=B+1.0
      IF(SAMPLE(K,I).GE.2.0.AND.SAMPLE(K,J).GE.2.0)C=C+1.0
      GO TO 50
  230 IF(SAMPLE(I,K).GE.2.0)A=A+1.0
      IF(SAMPLE(J.K).GE.2.0)B=B+1.0
      IF(SAMPLE(I,K).GE.2.0.AND.SAMPLE(J,K).GE.2.0)C=C+1.0
   50 CONTINUE
      IF(NL.EQ.2)GO TO 52
      FTAXON(I)=A
      IF(I.EQ.(NTAXA-1))FTAXON(NTAXA)=B
      GO TO 53
   52 FSAMPL(I)=A
      IF(I.EQ.(NSAMPL-1))FSAMPL(NSAMPL)=B
   53 CC(J,I)=C
      IF((B).GE.(A))GO TO 55
      TEMP=B
      B=A
      A=TEMP
   55 FC(I,J)=(C/SQRT(-1.0/(2.0*SQRT(B)))
      FC(J,I)=FC(I,J)
   56 A=0.0
      B=0.0
   60 C=0.0
C---- WRITE OUT THE MATRIX -FC- ON SCRATCH TAPE FOR INPUT INTO THE
C     CLUSTER PROGRAM.
```

```
      IF(NL.EQ.2)GO TO 370
      WRITE(9) NTAXA,((FC(I,J),I=1,NTAXA),J=1,NTAXA),((TAXNAM(I,J),
     1J=1,4),I=1,NTAXA),TITLE, TYPOUT,AMOM
      END FILE 9
      REWIND 9
      GO TO 450
  370 WRITE(10)NSAMPL,((FC(I,J),I=1,NSAMPL),J=1,NSAMPL),((SAMNAM(I,J),
     1J=1,4),I=1,NSAMPL),TITLE,TYPOUT,AMOM
      END FILE 10
      REWIND 10
C---- MULTIPLY -FC- BY 100 AND CONVERT TO INTEGER TO GET -FCX100-.
  450 DO 360 JJ=1,LIMIT2
      DO 360 KK=JJ,LIMIT2
      FC(JJ,KK)=FC(JJ,KK)*100.0
  360 FCX100(JJ,KK)=FC(JJ,KK)
C---- WRITE OUT TAXON OR SAMPLE NAME, FREQUENCY OF OCCURRENCE, FREQUENCY
C     OF JOINT OCCURRENCE, AND FAGER COEFFICIENT TIMES 100 IN A TAXON VS
C     TAXON OR SAMPLE VS SAMPLE MATRIX
      DO 300 NCOPY=1,2
      K=1
      KK=30
  105 WRITE(6,100)TITLE
  100 FORMAT(1H1,20X,12A6//)
      IF(NL.EQ.2)GO TO 180
C---- FIRST WRITE MATRIX FOR TAXA
      WRITE(6,150)
  150 FORMAT(1H0,10HTAXON NAME,14X,5HFREQ.,5X,54HJOINT OCCURRENCE INDEX
     1TIMES 100 (FCX100), UNCLUSTERED,//)
      WRITE(6,340)
  340 FORMAT(1H ,32X,67H(** INDICATES THAT A, B, OR C WAS ZERO OR THAT F
     1CX100 WAS NEGATIVE),//)
      DO 170 N=1,NTAXA
      M=KK
      IF(KK.GT.N)M=N
      MP1=M+1
      IF(MOD(N,51).EQ.0)WRITE(6,100)TITLE
      IF(N.GT.K)GO TO 190
      WRITE(6,140)(TAXNAM(N,L),L=1,4),FTAXON(N),(FCX100(N,I),I=K,KK)
  140 FORMAT(1H ,4A6,1X,I3,2X,30(1X,I2))
      GO TO 170
  190 IF(N.GE.KK)GO TO 195
      WRITE(6,140) (TAXNAM(N,L),L=1,4),FTAXON(N),(CC(N,I),I=K,M),
     1(FCX100(N,I),I=MP1,KK)
      GO TO 170
  195 WRITE(6,140)(TAXNAM(N,L),L=1,4),FTAXON(N),(CC(N,I),I=K,KK)
  170 CONTINUE
      GO TO 155
C---- NOW WRITE MATRIX FOR SAMPLES
  180 WRITE(6,240)
  240 FORMAT(1H0,11HSAMPLE NAME,13X,5HFREQ.,5X,41HJOINT OCCURRENCE INDEX
     1 TIMES 100 (FCX100),//)
      WRITE(6,340)
      DO 250 N=1,NSAMPL
      M=KK
      IF(KK.GT.N)M=N
      MP1=M+1
      IF(MOD(N,51).EQ.0)WRITE(6,100)TITLE
      IF(N.GT.K)GO TO 270
  260 WRITE(6,140)(SAMNAM(N,L),L=1,4),FSAMPL(N),(FCX100(N,I),I=K,KK)
      GO TO 250
  270 IF(N.GE.KK)GO TO 275
      WRITE(6,140)(SAMNAM(N,L),L=1,4),FSAMPL(N),(CC(N,I),
     1I=K,M),(FCX100(N,I),I=MP1,KK)
      GO TO 250
  275 WRITE(6,140)SAMNAM(N,L),L=1,4),FSAMPL(N),(CC(N,I),I=K,KK)
  250 CONTINUE
  155 WRITE(6,160)
  160 FORMAT(1H0,36X,38HJOINT FREQUENCY VALUE (C), UNCLUSTERED)
      K=K+30
      KK=KK+30
      WRITE(6,330)
  330 FORMAT(1H1/1H0/1H0)
      IF(K.GT.LIMIT2)GO TO 300
      IF(KK.GT.LIMIT2)KK=LIMIT2
      GO TO 105
  300 CONTINUE
      IF (PROCES.NE.3.0)GO TO 400
  350 CONTINUE
  400 STOP
      END
$DATA
```

```
$SETUP 9          TAPE
$SETUP 10         TAPE
$EXECUTE          IBJOB
$IBJOB            ALT10
$IBFTC CLUSTR
      DIMENSION GRPI(90), MVAL(4)
      DIMENSION NO(90),SVAL(90,90),SGRP(90),CS(4),TITLE(12),DESCR(90,4),
     1MARK(90,90),ISVAL(90,90)
      REAL MVAL,MARM,MMIN
      INTEGER GRP(90,90),FPL(90),FPR(90),NNN(90)
      INTEGER AA,BB,CC,DD,EE,FF,GG,HH
      EQUIVALENCE (GRP(1),MARK(1),ISVAL(1))
      LOGICAL XLEFT, XRIGHT
      COMMON /BLK/GRP,NO,SVAL,SGRP
      DATA AA/5H*****/,BB/5H ****/,CC/5H  ***/,DD/5H   **/,EE/5H    */,
     1FF/5H    +/,GG/5H    -/,HH/5H    ./
      READ(5,900) PROCES
  900 FORMAT (F5.1)
      DO 2000 III=1,2
      IF(PROCES.EQ.2.0)GO TO 700
      IF(III.EQ.2)GO TO 700
      REWIND 9
      READ(9) NOTU,((SVAL(I,J),I=1,NOTU),J=1,NOTU),
     1((DESCR(I,J),J=1,4),I=1,NOTU),TITLE,TYPOUT,AMOM
      WRITE(6,5000)((SVAL(I,J),I=1,10),J=1,10)
 5000 FORMAT(1H ,10F12.8)
      GO TO 800
  700 REWIND 10
      READ(10) NOTU,((SVAL(I,J),I=1,NOTU),J=1,NOTU),
     1((DESCR(I,J),J=1,4),I=1,NOTU),TITLE,TYPOUT,AMOM
  800 CONTINUE
C     WIPE OUT THE DIAGONAL AND INITIALIZE THE REST OF THIS MESS.
      DO 11 I=1,NOTU
      SVAL (I,I) = -1.0
      NO(I) = 1
      GRP(I,1)=I
      FPL(I) = 1
   11 FPR(I) = 1
C     NOW LET-S SEE IF WE CAN FIND A MAXIMUM S-VALUE.
     T=TIME(X)
   15 CONTINUE
      CALL XMAX(NOTU,IOTU,JOTU,SMAX)
C     FOUND IT.  THAT WAS EASY.
C     MOVE GROUPS. THAT-S HARD.
      SGRP(IOTU) = SMAX
      IF(AMOM.EQ.1.0) GO TO 99
      KJL = FPL(JOTU)
      KJR = FPR(JOTU)
      KIL=FPL(IOTU)
      KIR=FPR(IOTU)
  140 K1L=GRP(JOTU,KJL)
      K1R=GRP(JOTU,KJR)
      K2L=GRP(IOTU,KIL)
      K2R=GRP(IOTU,KIR)
C     NOW THAT WE HAVE THE 2 FOCAL PAIRS, WE MUST FIND THE CROSS-S VALUE
C     AND IN DOING SO WE MUST ALWAYS SELECT FRO STARBOARD SIDE OF
```

```
C     MATRIX BECAUSE THE OTHER SIDE IS GETTING KLOBBERED.
      IF(K1L.GT.K2L) GO TO 150
      CS(1) = SVAL(K1L,K2L)
      GO TO 160
  150 CS(1)=SVAL(K2L,K1L)
  160 IF(K1L.GT.K2R) GO TO 170
      CS(2) = SVAL(K1L,K2R)
      GO TO 180
  170 CS(2) = SVAL(K2R,K1L)
  180 IF(K1R.GT.K2L) GO TO 190
      CS(3) = SVAL(K1R,K2L)
      GO TO 200
  190 CS(3) = SVAL(K2L,K1R)
  200 IF(K1R.GT.K2R) GO TO 210
      CS(4) = SVAL(K1R,K2R)
      GO TO 220
  210 CS(4) = SVAL(K2R,K1R)
C     NOW FIND WHICH ONE IS THE MAXIMUM.
  220 IMAX=1
      CSMAX = CS(1)
      DO 230 I=2,4
      IF(CS(I).LE.CSMAX) GO TO 230
      CSMAX = CS(I)
      IMAX=I
  230 CONTINUE
C     ALRIGHT SO I FOUND ONE MAX, ARE THERE MORE.
      DO 240 I=1,4
      IF(I.EQ.IMAX) GO TO 240
      IMAX=I
      GO TO 310
  240 CONTINUE
C     NOW WE TURN THIS THING EVERY WAY BUT LOOSE
  250 GO TO(260,270,280,260),IMAX
C     ROTATE
  260 N = NO(JOTU)
      NO2 = N/2
      IF(N.EQ.0) GO TO 267
      DO 265 I=1,NO2
      K=N-I+1
      TEMP=GRP(JOTU,K)
      GRP(JOTU,K)=GRP(JOTU,I)
  265 GRP(JOTU,I)=TEMP
      KAY=FPR(JOTU)
      FPR(JOTU)=N-FPL(JOTU)+1
      FPL(JOTU)=N-KAY+1
  267 GO TO (280,270,280,270),IMAX
C     ADD
  270 NI=NO(IOTU)
      NIP1=NI+1
      NINJ=NI+NO(JOTU)
      DO 275 I=NIP1,NINJ
      K=I-NI
  275 GRP(IOTU,I)=GRP(JOTU,K)
      IF((NO(IOTU).EQ.1).AND.(NO(JOTU).NE.1)) FPL(IOTU)=FPL(JOTU)+1
      IF((NO(JOTU).EQ.1).AND.(NO(IOTU).NE. 1)) GO TO 290
      FPR(IOTU)=NO(IOTU)+FPR(JOTU)
      GO TO 290
C     PUSH
  280 NJ=NO(JOTU)
      NI=NO(IOTU)
      DO 285 I=1,NI
      K=NI-I+1
      L=K+NJ
  285 GRP(IOTU,L)=GRP(IOTU,K)
      DO 286 I=1,NJ
  286 GRP(IOTU,I)=GRP(JOTU,I)
      FPR(IOTU)=FPR(IOTU)+NO(JOTU)
      IF((NO(JOTU).EQ. 1).AND.(NO(IOTU).EQ. 1)) GO TO 290
      IF(NO(JOTU).EQ.1) GO TO 287
      FPL(IOTU)=FPL(JOTU)
      GO TO 290
  287 FPL(IOTU)=FPL(IOTU)+1
C     ZERO-OUT JOTU ROW
  290 DO 300 I=1,NJ
  300 GRP(JOTU,I)=0
      NO(IOTU)=NO(IOTU)+NO(JOTU)
      NO(JOTU)=0
      SGRP(JOTU)=0
      FPL(JOTU)=0
      FPR(JOTU)=0
      GO TO 20
C     LETS SEE IF WE CAN BREAK A TIE.
  310 IF(NO(JOTU).EQ.1) GO TO 250
      XLEFT=KIL.EQ.1
      XRIGHT=KIR.EQ.NO(IOTU)
      IF(XLEFT.AND.XRIGHT) GO TO 320
      IF(.NOT.XLEFT)KIL=KIL-1
      IF(.NOT.XRIGHT) KIR=KIR+1
      GO TO 140
  320 KIL=FPL(IOTU)
      KIR=FPR(IOTU)
      XLEFT=KJL.EQ.1
      XRIGHT=KJR.EQ.NO(JOTU)
      IF(XLEFT.AND.XRIGHT) GO TO 250
      IF(.NOT.XLEFT) KJL=KJL-1
      IF(.NOT.XRIGHT) KJR=KJR+1
      GO TO 140
99    II=NO(IOTU)
      JJ=NO(JOTU)
      DO 115 LO=1,4
      IF(II.EQ.1.AND.JJ.EQ.1) IMIN=1
      IF(II.EQ.1.AND.JJ.EQ.1)GO TO 232
      GO TO (100,105,100,111),LO
100   DO 101 IA=1,II
      GRPI(IA) =GRP(IOTU,IA)
101   CONTINUE
      GO TO (102,102,109,109),LO
102   DO 103 IA=1,JJ
      IB=IA+II+1
103   GRPI(IB)=GRP(JOTU,IA)
      GO TO 104
  105 DO 106 IA=1,JJ
      GRPI(IA)=GRP(JOTU,IA)
  106 CONTINUE
      GO TO (107,107,111,111),LO
  107 DO 108 IA=1,II
      IB=IA+JJ
      GRPI(IB)=GRP(IOTU,IA)
  108 CONTINUE
      GO TO 104
  109 DO 110 IA=1,JJ
      IB=JJ+II+1-IA
      GRPI(IB)=GRP(JOTU,IA)
  110 CONTINUE
      GO TO 104
  111 DO 112 IA=1,II
      IB=II-IA+1
      GRPI(IB)=GRP(IOTU,IA)
  112 CONTINUE
      DO 113 IA=1,JJ
      IB=II+IA
      GRPI(IB)=GRP(JOTU,JJ)
  113 CONTINUE
  104 MVAL(LO)=0.0
      III=II+JJ
      DO 114 I=1,III
      DO 114 J=1,I
      IA=GRPI(I)
      JA=GRPI(J)
      K=I-J
      X=K
      MARM=X/0.707
      MVAL(LO)=MVAL(LO)+(SVAL(IA,JA)*MARM)
  114 CONTINUE
  115 CONTINUE
      IMIN=1
      MMIN=MVAL(1)
      DO 231 I=2,4
      IF(MVAL(I).GT.MMIN) GO TO 231
      MMIN=MVAL(I)
      IMIN=I
  231 CONTINUE
  232 CONTINUE
      GO TO (281,271,261,261),IMIN
C     ROTATE
  261 N=NO(JOTU)
      NO2 = N/2
      IF(N.EQ.0)GO TO 268
      DO 266 I=1,NO2
      K=N-I+1
      TEMP=GRP(JOTU,K)
      GRP(JOTU,K)=GRP(JOTU,I)
  266 GRP(JOTU,I)=TEMP
  268 GO TO (281,271,281,271),IMIN
C     ADD
  271 NI=NO(IOTU)
      NIP1=NI+1
```

```
           NINJ=NI+NO(JOTU)
           DO 276 I=NIP1,NINJ
           K=I-NI
   276     GRP(IOTU,I)=GRP(JOTU,K)
           GO TO 291
   C       PUSH
   281     NJ=NO(JOTU)
           NI=NO(IOTU)
           DO 288 I=1,NI
           K=NI-I+1
           L=K+NJ
   288     GRP(IOTU,L)=GRP(IOTU,K)
           DO 289 I=1,NJ
   289     GRP(IOTU,I)=GRP(JOTU,I)
           GO TO 291
   C       ZERO-OUT JOTU ROW
   291     DO 301 I=1,NJ
   301     GRP(JOTU,I)=0
           NO(IOTU)=NO(IOTU)+NO(JOTU)
           NO(JOTU)=0
           SGRP(JOTU)=0
           GO TO 20
  C        NOW THAT WE HAVE ATTACHED THAT *$$/(,1 ON THE PROPER SIDE LET-S
  C        GO BACK TO THE WORKING MATRIX.
  C        FIRST - ZERO-OUT THE JOTU ROWS AND COLUMNS.
      20 JOTUM1=JOTU-1
         JOTUP1=JOTU+1
         DO 30 J=1,JOTUM1
      30 SVAL(JOTU,J) =-1.0
         DO 40 J=JOTUP1,NOTU
      40 SVAL(J,JOTU)=-1.0
  C      SECOND-RECOMPUTE IOTU ROWS AND COLUMNS
         IOTUM1=IOTU-1
         IOTUP1=IOTU+1
         DO 50 J=1,IOTUM1
         IF(SVAL(IOTU,J).GE.0.0) SVAL(IOTU,J)=AVG(IOTU,J)
      50 CONTINUE
         DO 60 J=IOTUP1,NOTU
         IF(SVAL(J,IOTU).GE.0.0) SVAL(J,IOTU)=AVG(J,IOTU)
      60 CONTINUE
         WRITE(6,77)
      77 FORMAT (1X)
         DO 75 I=1,NOTU
         KKK=GRP(I    ,1)
         KING=NO(I)
         IF(KING.LE.1) GO TO 75
         KKJ=GRP(I    ,KING)
 C------TO INCORPORATE WRITE-OUT OF FPL,FPR,SGRP ETC., OMIT THE COMMENT
 C       -C- AND FOLLOWING C-S IN THE NEXT TWO STATEMENTS.
         WRITE(6,79) FPL(I),FPR(I),KING,SGRP(I),(DESCR(KKK,J),J=1,4),
        1(DESCR(KKJ ,J),J=1,4)
      79 FORMAT (1X,313,F7.4,1X,4A6,1X,4A6)
      75 CONTINUE
 C---    TO PRINT OUT ITERATION TIME, REMOVE THE CCC FROM THE FOLLOWING
 C       THREE STATEMENTS.
 CCC     DT=TIME(X)-T
```

```
CCC   WRITE(6,78) DT
CCC78 FORMAT (18HOITERATION TIME = ,F8.2)
   76 CONTINUE
      DO 70 J=1,NOTU
      IF(NO(J).GE.NOTU) GO TO 80
   70 CONTINUE
      GO TO 15
   80 DO 342 I=1,NOTU
  342 SVAL(I,I)=1.0
      DO 350 I=2,NOTU
      K=I-1
      M=GRP(IOTU,I)
      DO 350 J=1,K
      L=GRP(IOTU,J)
      IF(M.GT.L) GO TO 345
      SVAL(I,J)=SVAL(M,L)
      GO TO 350
  345 SVAL(I,J)=SVAL(L,M)
  350 CONTINUE
      DO 413 I=1,NOTU
      NNN(I)=GRP(IOTU,I)
  413 CONTINUE
      DO 460 LOOP=1,3
      IF(TYPOUT.EQ.1.0)GO TO 1
      WRITE (6,901)
  901 FORMAT (1H1, 15HKFY TO MARKINGS,5X//
     15X, 43H***** INDICATES SVAL .GE. 0.80 AND .LE. 1.0//
     15X,44H  **** INDICATES SVAL .GE. 0.70 AND .LT. 0.80//
     25X,44H   *** INDICATES SVAL .GE. 0.60 AND .LT. 0.70//
     35X,44H    ** INDICATES SVAL .GE. 0.50 AND .LT. 0.60//
     45X,44H     * INDICATES SVAL .GE. 0.40 AND .LT. 0.50//
     55X,44H     + INDICATES SVAL .GE. 0.30 AND .LT. 0.40//
     65X,44H     - INDICATES SVAL .GE. 0.20 AND .LT. 0.30//
     75X,44H     . INDICATES SVAL .GE. 0.00 AND .LT. 0.20//)
      WRITE(6,410) TITLE
  410 FORMAT(1H1,26X,12A6)
      WRITE (6,412)
  412 FORMAT (9HOOTU NAME,57X,18HCLUSTERED S-VALUES/1HO)
      K=1
      L=17
      DO 600 I=1,NOTU
      DO 600 J=1,NOTU
      IF (SVAL(I,J).LT.0.20) MARK(I,J)=HH
      IF(SVAL(I,J).GE.0.20.AND. SVAL(I,J).LT.0.30) MARK(I,J) =GG
      IF(SVAL(I,J).GE.0.30.AND. SVAL(I,J).LT.0.40) MARK(I,J) =FF
      IF(SVAL(I,J).GE.0.40.AND. SVAL(I,J).LT.0.50) MARK(I,J) =EE
      IF(SVAL(I,J).GE.0.50.AND. SVAL(I,J).LT.0.60) MARK(I,J) =DD
      IF(SVAL(I,J).GE.0.60.AND. SVAL(I,J).LT.0.70) MARK(I.J) =CC
      IF(SVAL(I,J).GE.0.70.AND. SVAL(I,J).LT.0.80) MARK(I,J) =BB
      IF(SVAL(I,J).GE.0.80.AND. SVAL(I,J).LE.1.00) MARK(I,J) =AA
6 00  CONTINUE
  415 DO 420 I=1,NOTU
      M=L
      NN=NNN(I)
      IF(L.GT.I)M=I
      IF (MOD(I,51).EQ.O) WRITE (6,410) TITLE
      IF(M.LT.K) GO TO 417
      WRITE (6,430) (DESCR(NN,J),J=1,4),(MARK(I,J),J=K,M)
      GO TO 420
  417 WRITE(6,430)(DESCR(NN,J),J=1,4)
  420 CONTINUE
  430 FORMAT(1X,4A6,2X,17(1X,1A5))
      K=K+17
      L=K+16
      WRITE (6,450)
  450 FORMAT(1H1/1H0/1H0)
      IF(K.GT.NOTU)GO TO 460
      IF(L.GT.NOTU) L=NOTU
      GO TO 415
    1 WRITE(6,410)TITLE
      WRITE (6,412)
      K=1
      L=35
  416 DO 421 I=1,NOTU
      M=L
      NN=NNN(I)
      IF(L.GT.I)M=I
      IF (MOD(I,51).EQ.0) WRITE (6,410) TITLE
      IF (LOOP.GT.1) GO TO 1000
      DO 419 J=K,M
      SVAL(I,J)=SVAL(I,J)*100.0
  419 ISVAL(I,J)=SVAL(I,J)
 1000 CONTINUE
      IF(M.LT.K) GO TO 418
      WRITE(6,431)(DESCR(NN,J),J=1,4),(ISVAL(I,J),J=K,M)
      GO TO 421
  418 WRITE (6,431)(DESCR(NN,J),J=1,4)
  421 CONTINUE
  431 FORMAT(1X,4A6,2X,35(1X,1I2))
      K=K+35
      L=L+35
      WRITE (6,450)
      IF(K.GT.NOTU)GO TO 460
      IF(L.GT.NOTU) L=NOTU
      GO TO 416
  460 CONTINUE
      IF(PROCES.NE.3.0)GO TO 3000
 2000 CONTINUE
 3000 CONTINUE
      STOP
      END
$IBFTC MAX
      SUBROUTINE XMAX(NOTU,IOTU,JOTU,SMAX)
      DIMENSION NO(90),SVAL(90,90),SGRP(90)
      INTEGER GRP(90,90)
      COMMON /BLK/ GRP,NO,SVAL, SGRP
      SMAX=-1.0
      NOTUM1=NOTU-1
      DO 10 J=1,NOTUM1
      K=J+1
      DO 10 I=K,NOTU
      IF(SVAL(I,J).LE.SMAX) GO TO 10
      SMAX=SVAL(I,J)
      IOTU=I
      JOTU=J
   10 CONTINUE
      RETURN
      END
$IBFTC AVER
      REAL FUNCTION AVG(I,J)
      INTEGER GRP(90,90)
      DIMENSION NO(90),SVAL(90,90),SGRP(90)
      COMMON /BLK/GRP,NO,SVAL,SGRP
      NO1=NO(I)
      NO2=NO(J)
      EN=0.0
      SUM=0.0
      DO 30 L=1,NO1
      LL=GRP(I,L)
      DO 30 M=1,NO2
      MM=GRP(J,M)
      IF(LL.LT.MM) GO TO 25
      SUM=SUM+SVAL(MM,LL)
      GO TO 30
   25 SUM=SUM+SVAL(LL,MM)
   30 EN=NO1*NO2
      AVG=SUM/EN
      RETURN
      END
$DATA
  3.0




$EOF
```

```
$JOB              AB,2,1000         3GA81DO BUCHANAN, R. J.
$ID
$EXECUTE
$IBJOB
$IBFIC GRPLST
C    ******************************************************************************
C      THIS PROGRAM READS THE TAXON OCCURRENCE DATA FOR ALL SAMPLES IN A
C      GROUP AND WRITES, IN DUPLICATE, A TABLE WITH THE FOLLOWING INFORM-
C      ATION --
C         1) TAXON NAME.
C         2) FREQUENCY OF DETECTION AT ANY ABUNDANCE LEVEL.
C         3) FREQUENCY OF OCCURRENCE AT 5 OR MORE CELLS/ML.
C         4) NUMBER OF TAXA DETECTED IN THE SAMPLE GROUP.
C         5) NUMBER OF TAXA PRESENT AT 5 OR MORE CELLS/ML IN THE SAMPLE
C            GROUP.
C                                            == R. J. BUCHANAN
C    ******************************************************************************
C
      DIMENSION FMT(84),SAMPLE(120,100),TAXNAM(120,4),IOCURD(120),IABUND
     1(120)
      DATA ((SAMPLE(I,J),I=1,120),J=1,10))/12000*0.0/,(IOCURD(I),I=I,120
     1)/120*0/,(IABUND(I),I=1,120)/120*0/,L,M/2*0/
      READ(5,10)NSAMPL,NTAXA,IGRPNO
   10 FORMAT(315)
      READ(5,20)FMT
   20 FORMAT(12A6)
      READ(5,FMT)((SAMPLE(I,J),I=1,NTAXA),J=1,NSAMPL)
      READ(5,30)((TAXNAM(I,J),J=1,4),I=1,NTAXA)
   30 FORMAT(4A6)
      DO 40 I=1,NTAXA
      DO 40 J=1,NSAMPL
      IF(SAMPLE(I,J).GE.1.0)IOCURD(I)=IOCURD(I)+1
      IF(SAMPLE(I,J).GE.2.0)IABUND(I)=IABUND(I)+1
   40 CONTINUE
      DO 70 N=1,NTAXA
      IF(IOCURD(N).GE.1)L=L+1
      IF(IABUND(N).GE.1)M=M+1
   70 CONTINUE
      DO 100 K=1,2
      WRITE(6,50)IGRPNO
   50 FORMAT(1H1,60HTABULATION OF THE OCCURRENCE FREQUENCY OF ALL TAXA I
     1N GROUP ,I3,1H.,//1X,13HORGANISM NAME,17X,8HDETECTED,11X,20HPRESEN
     2T 5 OR MORE/ML,//)
      DO 60 I=1,NTAXA
      WRITE(6,75)(TAXNAM(I,J),J=1,4),IOCURD(I),IABUND(I)
   75 FORMAT(1X,4A6,I12,I23)
      IF(MOD(I,50).EQ.0)WRITE(6,50)IGRPNO
   60 CONTINUE
      WRITE(6,80)IGRPNO,L
   80 FORMAT(1H0,33HNUMBER OF 1AXA DETECTED IN GROUP ,I3,2H =,I4,1H.)
      WRITE(6,90)IGRPNO,M
   90 FORMAT(1H0,54HNUMBER OF TAXA PRESENT AT 5 OR MORE CELLS/ML IN GROU
     1P ,I3,2H =,I4,1H.)
  100 CONTINUE
      STOP
      END
```

```
$JOB             AB,1,1000       3GA81DO BUCHANAN, R. J.
$ID
$EXECUTE
$IBJOB
$IBFTC ANALYS
C    *************************************************************************
C    * THIS PROGRAM IS DESIGNED TO PROCESS PHYSICAL AND CHEMICAL DATA        *
C    * RELATING TO SAMPLES, EITHER AS A LARGE HETEROGENEOUS GROUP OF         *
C    * SAMPLES LUMPED INDESCRIMINANTLY, OR AS SAMPLE GROUPS DIFFERENTIAT-    *
C    * ED BY NUMERICO-TAXONOMIC TECHNIQUES. A SAMPLE GROUP MAY BE AS         *
C    * LARGE AS 200 SAMPLES.  THE NUMBER OF VARIABLES RELATED TO THE         *
C    * SAMPLE GROUPS MAY BE AS LARGE AS 20.                                  *
C    *                                                                       *
C    * THREE KINDS OF TABLES ARE PRINTED IN DUPLICATE - -                    *
C    *    1) CHEMICAL AND PHYSICAL DATA ASSOCIATED WITH EACH SAMPLE.         *
C    *    2) BIOLOGICAL DATA ASSOCIATED WITH EACH SAMPLE.                    *
C    *    3) STATISTICAL SUMMARIES OF THE VARIABILITY OF EACH VARIABLE,      *
C    *        AS RELATED TO THE ENTIRE SAMPLE GROUP.                         *
C    *                                                                       *
C    * THREE KINDS OF DATA CARDS ARE READ - -                                *
C    *    1) ONE CARD WITH GROUP SIZE, NUMBER, AND THE NUMBER OF VARIABLES   *
C    * RELATED TO THE SAMPLE GROUP.                                          *
C    *    2) CARDS WITH THE NAMES OF VARIABLES RELATED TO THE SAMPLE GROUP.  *
C    *    3) THE SAMPLE DATA CARDS FOR THOSE SAMPLES INCLUDED IN THE GROUP.  *
C    *                                                                       *
C    *                          = = R. J. BUCHANAN                           *
C    *                                                                       *
C    *************************************************************************
      DIMENSION SAMNAM(200),DATE(200),TEMP(200),COND(200),ALPHA(200),
     1CARBON(200),TOTSES(200),COMSES(200),PTCSES(200),CHLORA(200),ACIDER
     2(200),PO4P(200),ATPO4P(200),TOTALP(200),ATTOTP(200),NO3N(200),
     3ATNO3N(200),NH4N(200),NOVERP(200),SECCHI(200),METSEC(200),VARBL(20
     40),RATIO1(200),RATIO2(200),RATIO3(200),MEAN(20),STDDEV(20),COEFDV
     5(20),NSAMPL(20),VARNAM(20,4)
      COMMON VARBL,MEAN,STDDEV,COEFDV,IVARBL,NSAMPL,GRPSIZ
      INTEGER GRPNO,GRPSIZ
      REAL,NO3N,METSEC,N114N,MEAN,NOVERP
      DATA (TEMP(I),I=1,200)/200*0.0/,(COND(I),I=1.200)/200*0.0/,(ALPHA
     1(I),I=1,200)/200*0.0/,(CARBON(I),I=1,200)/200*0.0.(TOTSES(I),I=
     21,200)/200*0.0/.(COMSES(I),I=1,200)/200*0.0/,(PTCSES(I),I=1,200)/
     3200*0.0/,(CHLORA(I),I=1,200)/200*0.0/,(ACIDFR(I),I=1,200)/200*0.0/
     4,(PO4P(I),I=1,200)/200*0.0/,(TOTALP(I),I=1,200)/200*0.0/,(NO3N(I),
     5I=1,200)/200*0.0/,(NH4N(I),I=1,200)/200*0.0/,(SECCHI(I),I=1,200)/
     6200*0.0/
C---- READ GROUP NUMBER, GROUP SIZE, NUMBER OF VARIABLES CONSIDERED.
      READ(5,10)GRPNO,GRPSIZ,NVARBL
   10 FORMAT(315)
C---- READ SAMPLE DATA COLLECTED.
      DO 20 N=1,GRPSIZ
      READ(5,30)SAMNAM(N),DATE(N),TEMP(N),COND(N),ALPHA(N),CARBON(N),
     1COMSES(N),TOTSES(N),CHLORA(N),ACIDFR(N),PO4P(N),TOTALP(N),NO3N(N),
     2NH4N(N),SECCHI(N)
   30 FORMAT(2A6,F4.1,F5.0,F5.2,F6.3,2F5.2,F6.1,F4.2,2F5.3,2F5.2,F4.1)
   20 CONTINUE
      DO 36 N=1,GRPSIZ
      WRITE(6,35)SAMNAM(N),DATE(N),TEMP(N),COND(N),ALPHA(N),CARBON(N),
     1COMSES(N),TOTSES(N),CHLORA(N),ACIDFR(N),PO4P(N),TOTALP(N),NO3N(N),
     2NH4N(N),SECCHI(N)
   35 FORMAT(1X2A6,F8.1,F9.0,F9.2,F9.3,2F9.2,F9.1,F8.1,2F9.3,2F9.2,F8.1)
   36 CONTINUE
C---- CONVERT SECCHI DEPTH TO METRIC, CALCULATE PERCENTAGE OF SESTON
C---- WHICH WAS COMBUSTIBLE, RATIO BETWEEN TOTAL SESTON AND ALPHA,
C---- BETWEEN COMBUSTIBLE SESTON AND ALPHA, AND PARTICULATE CARBON AND ALPH
      DO 40 N=1,GRPSIZ
      METSEC(N)=SECCHI(N)*0.3048
      PTCSES(N)=(COMSES(N)/TOTSES(N))*100.00
      RATIO1(N)=TOTSES(N)/ALPHA(N)
      RATIO2(N)=COMSES(N)/ALPHA(N)
      RATIO3(N)=CARBON(N)/ALPHA(N)
C---- CONVERT ORTHO PHOSPHATE, TOTAL PHOSPHATE, AND NITRATE NITROGEN
C---- FROMMG/L TO MG ATOMS/L.
      ATPO4P(N)=PO4P(N)/30.974
      ATTOTP(N)=TOTALP(N)/30.974
      ATNO3N(N)=NO3N(N)/14.007
C---- DETERMINE THE ATOM RATIO BETWEEN NO3-N AND ORTHO PO4-P.
      NOVERP(N)=ATNO3N(N)/ATPO4P(N)
   40 CONTINUE
      DO 60 I=1,2
C---- WRITE OUT THE PHYSICAL/CHEMICAL DATA FOR ALL SAMPLES IN DUPLICATE.
      WRITE(6,90)
   90 FORMAT(1H1,9X,6HSAMPLE,22X,93HCONDUCT.     SECCHI  ATTENUATION  OR
     1THO PO4-P TOTAL PO4-P     NO3-N       NH4-N  RATIO NO3-N,/,1X,10X
     2,119HSITE   DATE       TEMP.(C)   (MMHOS)       (M)     COEF.(/M)
     3  (MG/L)      (MG/L)         (MG/L)         (MG/L)  TO ORTHO-P,//)
      DO 50 N=1,GRPSIZ
      IF(MOD(N,45).EQ.0)WRITE(6,90)
      WRITE(6,70)SAMNAM(N),DATE(N),TEMP(N),COND(N),METSEC(N),ALPHA(N),
     1PO4P(N),TOTALP(N),NO3N(N),NH4N(N),NOVERP(N)
   70 FORMAT(1X,8X,2A6,3X,F11.1,F10.0,F11.2,F13.2,2F12.3,3F12.2)
   50 CONTINUE
C---- WRITE OUT THE BIOLOGICAL DATA FOR ALL SAMPLES IN DUPLICATE.
      WRITE(6,100)
  100 FORMAT(1H1,52X,7HPERCENT,4X,11HPARTICULATE,24X,2(5HRATIO,7X),5HRAT
     1IO,/,1X,8X,6HSAMPLE,9X,105HTOTAL SESTON COMBUSTIBLE   COMBUSTIBLE
     2   CARBON   CHLOROPH. A    ACID   TOT.SES./   COMB.SES./   CARBON/
     3,/,1X,9X,118HSITE    DATE         (MG/L)      SESTON(MG/L)      SESTON
     4   (MG/L)    (MICROG./L)   FACTOR     ALPHA          ALPHA         ALPHA,
     5//)
      DO 60 N=1,GRPSIZ
      IF(MOD(N,45).EQ.0)WRITE(6,100)
      WRITE(6,80)SAMNAM(N),DATE(N),TOTSES(N),COMSES(N),PTCSES(N),CARBON
     1(N),CHLORA(N),ACIDFR(N),RATIO1(N),RATIO2(N),RATIO3(N)
   80 FORMAT(1X,7X,2A6,1X,2F12.2,2X,F12.2,F12.3,F12.1,F12.2,F10.2,F12.2,
     1F12.5)
   60 CONTINUE
C---- IFIT IS DESIRED TO OMIT THE FOLLOWING SECTION, REMOVE THE C-S FROM
C---- IN FRONT OF THE NEXT STATEMENT
CCCC  GO TO 330
C---- SEQUENTIALLY COMPUTE THE MEAN, STANDARD DEVIATION, AND COEFFICIENT
```

```
C---- OF VARIATION FOR EACH VARIABLE MEASURED, BASED ON WHATEVER DATA
C---- ARE AVAILABLE.  TRANSCRIBE ALL DATA FOR EACH VARIABLE INTO A
C---- -SCRATCH- ARRAY, AND PROCESS THEM BY SUBROUTINE -CALCUL-, ONE
C---- VARIABLE AT A TIME.
      IVARBL=1
      DO 110 I=1,GRPSIZ
      VARBL(I)=TEMP(I)
  110 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      INVARBL=2
      DO 120 I=1,GRPSIZ
      VARBL(I)=COND(I)
  120 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      INVARBL=3
      DO 130 I=1,GRPSIZ
      VARBL(I)=METSEC(I)
  130 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=4
      DO 140 I=1,GRPSIZ
      VARBL(I)=ALPHA(I)
  140 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=5
      DO 150 I=1,GRPSIZ
      VARBL(I)=PO4P(I)
  150 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=6
      DO 160 I=1,GRPSIZ
      VARBL(I)=TOTALP(I)
  160 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=7
      DO 170 I=1,GRPSIZ
      VARBL(I)=NO3N(I)
  170 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=8
      DO 180 I=1,GRPSIZ
      VARBL(I)=NH4N(I)
  180 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=9
      DO 190 I=1,GRPSIZ
      VARBL(I)=NOVERP(I)
  190 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=10
      DO 200 I=1,GRPSIZ
      VARBL(I)=TOTSES(I)
  200 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=11
      DO 210 I=1,GRPSIZ
      VARBL(I)=COMSES(I)
  210 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=12
      DO 220 I=1,GRPSIZ
      VARBL(I)=PTCSFS(I)
  220 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=13
      DO 230 I=1,GRPSIZ
      VARBL(I)=CARBON(I)
  230 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=14
      DO 240 I=1,GRPSIZ
      VARBL(I)=CHLORA(I)
  240 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=15
      DO 250 I=1,GRPSIZ
      VARBL(I)=ACIDFR(I)
  250 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=16
      DO 260 I=1,GRPSIZ
      VARBL(I)=RATIO1(I)
  260 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=17
      DO 270 I=1,GRPSIZ
      VARBL(I)=RATIO2(I)
  270 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      IVARBL=18
      DO 280 I=1,GRPSIZ
      VARBL(I)=RATIO3(I)
  280 CONTINUE
      CALL CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
C---- WRITE OUT THE STATISTICS COMPUTED FOR EACH VARIABLE IN TABULAR FORM
C---- IN DUPLICATE.
      DO 320 J=1,2
      WRITE(6,290)GRPNO
  290 FORMAT(1H1,76HSTATISTICAL ASPECTS OF THE MEASURED VARIABLES ASSOCI
     1ATED WITH SAMPLE GROUP   ,I2,1H.)
      WRITE(6,300)
  300 FORMAT(1H0,7X,96HVARIABLE                    NO. OF SAMPLES    GROUP MEAN
     1  STANDARD DEVIATION    COEFFICIENT OF VARIATION)
      DO 320 K=1,NVARBL
      WRITE(6,310)(VARNAM(K,N),N=1,4),NSAMPL(K),MEAN(K),STDDEV(K),COEFDV
     1(K)
  310 FORMAT(1H0,4A6,9X,I3,10X,F8.3,9X,F8.3,14X,F8.3)
  320 CONTINUE
  330 STOP
      END

$IBFTC CALCL
```

```
      SUBROUTINE CALCUL(IVARBL,NSAMPL,GRPSIZ,VARBL,MEAN,STDDEV,COEFDV)
      DIMENSION VARBL(200),VRBLSQ(200),MEAN(20),STDDEV(20),COEFDV(20),
     1NSAMPL(20)
      COMMON VARBL,MEAN,STDDEV,COEFDV,IVARBL,NSAMPL,GRPSIZ
      INTEGER GRPSIZ
      REAL MEAN
      A=0.0
      SUM=0.0
      SUMSQ=0.0
      DO 10 N=1,GRPSIZ
      IF(VARBL(N).EQ.0.0)GO TO 10
      A=A+1.0
      SUM=SUM+VARBL(N)
      VRBLSQ=VARBL(N)**2
      SUMSQ=SUMSQ+VRBLSQ
   10 CONTINUE
      IF(SUM.EQ.0.0)GO TO 20
      MEAN(IVARBL)=SUM/A
      NSAMPL(IVARBL)=A
      STDDEV(IVARBL)=SQRT(ABS((SUMSQ/A)-MEAN(IVARBL)**2))
      COEFDV(IVARBL)=(STDDEV(IVARBL)/MEAN(IVARBL))*100.0
   20 CONTINUE
      RETURN
      END
$DATA
    0   10   18
TEMPERATURE (C)
CONDUCTIVITY (MILLIMHOS)
SECCHI DISC DEPTH (M)
ATTENUATION COEFFICIENT
ORTHO PHOSPHATE P (MG/L)
TOTAL PHOSPHATE P (MG/L)
NITRATE NITROGEN (MG/L)
AMMONIUM NITROGEN (MG/L)
NO3-N/ORTHO PO4-P RATIO
TOTAL SESTON (MG/L)
COMBUSTIBLE SESTON(MG/L)
PERCENT COMB. SESTON
PARTICULATE CARBON(MG/L)
CHLOROPHYLL A (MICROG/L)
ACID FACTOR (F(O)/F(A))
TOTAL SESTON/ALPHA RATIO
COMB. SESTON/ALPHA RATIO
PART. CARBON/ALPHA RATIO
FICT.  01/351111111111111111111111111111111111111111111111111111111111111111
FICT.  02/351111111111111111111111111111111111111111111111111111111111111111
FICT.  03/351111111111111111111111111111111111111111111111111111111111111111
FICT.  04/351111111111111111111111111111111111111111111111111111111111111111
FICT.  05/351111111111111111111111111111111111111111111111111111111111111111
FICT.  06/351111111111111111111111111111111111111111111111111111111111111111
FICT.  07/351111111111111111111111111111111111111111111111111111111111111111
FICT.  08/351111111111111111111111111111111111111111111111111111111111111111
FICT.  09/351111111111111111111111111111111111111111111111111111111111111111
FICT.  10/351111111111111111111111111111111111111111111111111111111111111111
$EOF
```

```
$JOB             AB,5,5000        3GA81DO BUCHANAN, R. J.
$ID
$ID
$EXECUTE
$IBJOB
$IBFTC SMCP
C     ************************************************************************
C
C      SIMPLE MINDED CORRELATION PROGRAM FOR FOUR FITS (SMCP)
C
C      THIS PROGRAM WILL CALCULATE THE LEAST SQUARES EQUATION THROUGH
C      DATA POINTS INVOLVING TWO VARIABLES. THE REGRESSION EQUATION MAY
C      BE CALCULATED FOR FOUR DIFFERENT RELATIONSHIPS -
C                    DEPENDENT VARIABLE        INDEPENDENT VARIABLE
C
C                    LINEAR                    LINEAR
C                    LINEAR                    LOG. BASE 10
C                    LOG. BASE 10              LINEAR
C                    LOG. BASE 10              LOG. BASE 10
C
C      THE DATA POINTS ARE PLOTTED ON A LINEAR/LINEAR GRAPH FOR EACH PAIR
C      OF VARIABLES ANALYSED. THE OUTPUT INCLUDES THE FOLLOWING -
C      CORRELATION OF X VS. Y (Y=A+BX), A VALUE, B VALUE, STD. DEVIATION
C      X AND Y DIRECTION, STD. ERROR OF MEAN OF X AND Y, COEF. OF
C      CORRELATION, AND STD. ERROR OF ESTIMATE.
C
C                                  DECK SET-UP
C
C      $DATA
C      CARD 1 -      TOTAL NO. OF VARIABLES(15 FORMAT).
C      CARD 2 -      FORMAT USED IN DATA CARDS (12A6 FORMAT, IN PARENTHESES)
C      CARD 3 -      NO. OF DATA CARDS (15 FORMAT).
C      DATA CARDS (FORMAT SPECIFIED ON CARD 2).
C      AN EXAMPLE OF A TYPICAL DATA CARD MAY BE -
C    -------
C    DATA FIELD NO.  1          2         3          4
C    CARD COL. NO.  5-9       10-14     20-25      30-40
C    DATA           DATE     LOCATION    SEX     EXPERIENCE
C    -------
C      CARD 4 -      TOTAL NUMBER OF CORRELATIONS TO BE CALCULATED (15).
C      CARD 5 -      NUMBER OF FITS FOR A GIVEN PAIR OF VARIABLES, INDEP-
C                    ENDENT VARIABLE, DEPENDENT VARIABLE, AND FIT NUMBER(S).
C                    THE FIT NUMBERS ARE FIT1 (LINEAR/LINEAR),FIT2 (LINEAR
C                    /LOG), FIT3 (LOG/LINEAR), AND FIT4 (LOG/LOG).  FORMAT
C                    IS 715. AN EXAMPLE CARD CALLING FOR FIT1 AND FIT4,
C                    USING VARIABLES 7 AND 8 FOLLOWS.
C    -------
C    CARD COL. NO.   5   10   15   20   25   30   35
C    PUNCHED NO.     2    7    8    4    1
C      NOTE THAT FIT NUMBERS MAY BE IN ANY ORDER BUT MUST BE LEFT-
C      JUSTIFIED WITH RESPECT TO THE FIT FIELDS. (I.E., IF 2 FITS ARE
C      CALLED, USE THE LEFTMOST 2 FIT FIELDS, LEAVING NO BLANK FIT FIELDS
C      TO THE LEFT OF ANY FIT NUMBER).
C    -------
C      CARD 6 -      MAXIMUM VALUES OF X AND Y VARIABLES TO SET THE
C                    LIMITS FOR THE UNIV. OF MICH. PLOT. VALUES SHOULD BE
```

```
C                    ROUNDED TO CONVENIENT VALUES FOR READING THE GRAPH
C                    (2F5.0 FORMAT).
C     CARD 7 -       TITLE OF GRAPH (12A6 FORMAT).
C     CARD 8 -       TITLE OF X-AXIS (12A6  FORMAT).
C
C     WHEN MORE THAN ONE PAIR OF VARIABLES ARE TO BE CORRELATED, CARDS
C     5 THRU 8 MUST BE SUPPLIED SPECIFYING THE DESIRED VARIABLE NUMBERS,
C     FIT NUMBERS, AND TITLES. A SERIES OF CARDS 5 THRU 8 IS REQUIRED
C     FOR EACH SET OF VARIABLES ANALYSED. CARD 4 MUST REFLECT THE TOTAL
C     NUMBER OF CORRELATIONS OF ALL SET TO BE CALCULATED.
C     $EOF
C     ********************************************************************************
      DIMENSION XY(20000),FMT(12),IFIT(10),DUMMY(900),TEMP1(500),
     1TEMP2(500),TITLE(12),XAXIS(12)
      COMMON XY,NVAR,NTOTAL,NDATA
   10 READ(5,20) NVAR,FMT
   20 FORMAT(15/12A6)
   60 READ(5,70)NDATA
   70 FORMAT(15)
      IF(NDATA*NVAR - 20000) 100,100,80
   80 WRITE(6,90)
   90 FORMAT(46H1NUMBER OF DATA ITEMS EXCEEDS LIMITS SPECIFIED)
  100 NTOTAL = NDATA*NVAR
      READ(5,FMT) (XY(I),I=1,NTOTAL)
      WRITE(6, 190) NTOTAL,(XY(I),I=1,NTOTAL)
  190 FORMAT(15/(7F10.4))
      READ(5,70) NCORR
      DO 170 JAY =1,NCORR
      READ(5,120) NFIT,IX,IY,(IFIT(I),I=1,NFIT)
  120 FORMAT(715)
      READ(5,121)XMAX,YMAX
  121 FORMAT(2F5.0)
      READ(5,200) TITLE
      READ(5,200) XAXIS
  200 FORMAT(12A6)
      XMIN=0.
      YMIN=0.
      CALL PLOT2 (DUMMY,XMAX,XMIN,YMAX,YMIN)
      ISTART= IX
      IEND= NTOTAL -(NVAR -IX)
      J= 1
      DO 210 I= ISTART,IEND,NVAR
      TEMP1(J)= XY(I)
  210 J= J+1
      ISTART= IY
      IEND= NTOTAL -(NVAR -IY)
      J= 1
      DO 220 I= ISTART,IEND,NVAR
      TEMP2(J)= XY(I)
  220 J= J+1
      CALL PLOT3 (1H*,TEMP1,TEMP2,NDATA)
      WRITE (6,230) TITLE
  230 FORMAT (1H1,20X,12A6)
      CALL FPLOT4 (35,35H                                  Y AXIS)
      WRITE (6,240) XAXIS
  240 FORMAT (1HO,20X,12A6)
```

```
      DO 170 KAY =1,NFIT
      ITYPE = IFIT(KAY)
      IF(ITYPE) 170,170,125
  125 GO TO (130,140,150,160),ITYPE
  130 CALL FIT1 (IX,IY)
      GO TO 170
  140 CALL FIT2(IX,IY)
      GO TO 170
  150 CALL FIT3(IX,IY)
      GO TO 170
  160 CALL FIT4(IX,IY)
  170 CONTINUE
      WRITE(6,180)
  180 FORMAT(12H1END OF PASS)
      GO TO 10
      END
$IBFTC FIT1.
      SUBROUTINE FIT1(IX,IY)
      DIMENSION XY(20000),SUM(8)
      COMMON XY,NVAR,NTOTAL,NDATA
      DO 10 I=1,8
   10 SUM(I)=0.0
      KX=IX-1
      KY=IY-1
      DO 15 I=1,NTOTAL,NVAR
      JAY=I+KX
      KAY =I+KY
      SUM(1)=SUM(1)+XY(JAY)
      SUM(2)=SUM(2)+XY(KAY)
      SUM(3)=SUM(3)+XY(JAY)*XY(KAY)
      SUM(4)=SUM(4)+XY(JAY)**2
   15 SUM(5)=SUM(5)+XY(KAY)**2
      FN=NDATA
      B=(SUM(3)-SUM(1)*SUM(2)/FN)/(SUM(4)-SUM(1)**2/FN)
      A=SUM(2)/FN-B*SUM(1)/FN
      SIGMAX=(SUM(4)/FN-(SUM(1)/FN)**2)**0.5
      SIGMAY=(SUM(5)/FN-(SUM(2)/FN)**2)**0.5
      SIGXM=SIGMAX/(FN-1.0)**0.5
      SIGYM=SIGMAY/(FN-1.0)**0.5
      DO 20 I=1,NTOTAL,NVAR
      JAY=I+KX
      KAY=I+KY
      YPR=A+B*XY(JAY)
      SUM(6)=SUM(6)+YPR
      SUM(7)=SUM(7)+YPR**2
      SUM(8)=SUM(8)+(XY(KAY)-YPR)**2
   20 CONTINUE
      SIGYPR=(SUM(7)/FN - (SUM(6)/FN)**2)**0.5
      RXY=SIGYPR/SIGMAY
      SXY=(SUM(8)/(FN-1.0))**0.5
      WRITE(6,30)IX,IY
   30 FORMAT(1H1,25H CORRELATION OF X VS. Y (,I3,4H VS.,I3,1H),//,13H Y
     1= A + B(X),//)
      WRITE(6,40)A,B,SIGMAX,SIGMAY,SIGXM,SIGYM,RXY,SXY
   40 FORMAT(4H A =,F10.4/4H B =,F10.4//24H STD. DEVIATION X DIR. =F10.4
     1/24H STD. DEVIATION Y DIR. =,F10.4//26H STD. ERROR OF MEAN OF X =,
     2F10.4/26H STD. ERROR OF MEAN OF Y =,F10.4//29H COEFFICIENT OF CORR
     3ELATION =,F10.4//25H STD. ERROR OF ESTIMATE =,F10.4)
      WRITE(6,250) NDATA
  250 FORMAT(1HO,20HNO. OF DATA PAIRS = ,I5)
      RETURN
      END
$IBFTC FIT2.
      SUBROUTINE FIT2(IX,IY)
      DIMENSION XY(20000),SUM(8)
      COMMON XY,NVAR,NTOTAL,NDATA
      DO 10 I=1,8
   10 SUM(I)=0.0
      KX=IX-1
      KY=IY-1
      DO 15 I=1,NTOTAL,NVAR
      JAY=I+KX
      KAY=I+KY
      SUM(1)=SUM(1)+XY(JAY)
      SUM(4)=SUM(4)+XY(JAY)**2
      IF(XY(KAY).EQ.0.0)GO TO 15
      YL=0.434294*ALOG(XY(KAY))
      SUM(2)=SUM(2)+YL
      SUM(3)=SUM(3)+XY(JAY)*YL
      SUM(5)=SUM(5)+YL**2
   15 CONTINUE
      FN=NDATA
      B = (SUM(3)-SUM(1)*SUM(2)/FN)/(SUM(4)-SUM(1)**2/FN)
      A=SUM(2)/FN-B*SUM(1)/FN
      SIGMAX=(SUM(4)/FN-(SUM(1)/FN)**2)**0.5
      SIGMAY=(SUM(5)/FN-(SUM(2)/FN)**2)**0.5
      SIGXM=SIGMAX/(FN-1.0)**0.5
      SIGYM=SIGMAY/(FN-1.0)**0.5
      DO 20 I=1,NTOTAL,NVAR
      JAY=I+KX
      KAY=I+KY
      YPR=A+B*XY(JAY)
      SUM(6)=SUM(6)+YPR
      SUM(7)=SUM(7)+YPR**2
      IF(XY(KAY).EQ.0.0)GO TO 20
      SUM(8)=SUM(8)+(0.434294*ALOG(XY(KAY))-YPR)**2
   20 CONTINUE
      SIGYPR=(SUM(7)/FN-(SUM(6)/FN)**2)**0.5
      RXY=SIGYPR/SIGMAY
      SXY=(SUM(8)/(FN-1.0))**0.5
      WRITE(6,30)IX,IY
   30 FORMAT(1H1,30H CORRELATION OF X VS. LOG(Y) (,I3,4H VS.,5H LOG(,I3,
     11H),//,18H LOG(Y) = A + B(X),//)
      WRITE(6,40)A,B,SIGMAX,SIGMAY,SIGXM,SIGYM,RXY,SXY
   40 FORMAT(4H A =,F10.4/4H B =,F10.4//24H STD. DEVIATION X DIR. =F10.4
     1/24H STD. DEVIATION Y DIR. =,F10.4//26H STD. ERROR OF MEAN OF X =,
     2F10.4/26H STD. ERROR OF MEAN OF Y =,F10.4//29H COEFFICIENT OF CORR
     3ELATION =,F10.4//25H STD. ERROR OF ESTIMATE =,F10.4
      WRITE(6,250) NDATA
  250 FORMAT(1HO,20HNO.OF  DATA PAIRS = ,I5)
      RETURN
      END
```

```
$IBFTC FIT3.
      SUBROUTINE FIT3(IX,IY)
      DIMENSION XY(20000),SUM(8)
      COMMON XY,NVAR,NTOTAL,NDATA
      DO 10 I=1,8
   10 SUM(I)=0.0
      KX=IX-1
      KY=IY-1
      DO 15 I=1,NTOTAL,NVAR
      JAY=I+KX
      KAY=I+KY
      SUM(2)=SUM(2)+XY(KAY)
      SUM(5)=SUM(5)+XY(KAY)**2
      IF(XY(JAY).EQ.0.0)GO TO 15
      XL=0.434294*ALOG(XY(JAY))
      SUM(1)=SUM(1)+XL
      SUM(3)=SUM(3)+XL*XY(KAY)
      SUM(4)=SUM(4)+XL**2
   15 CONTINUE
      FN=NDATA
      B=(SUM(3)-SUM(1)*SUM(2)/FN)/(SUM(4)-SUM(1)**2/FN)
      A=SUM(2)/FN-B*SUM(1)/FN
      SIGMAX = (SUM(4)/FN -(SUM(1)/FN)**2 )**0.5
      SIGMAY = (SUM(5)/FN -(SUM(2)/FN)**2 )**0.5
      SIGXM=SIGMAX/(FN-1.0)**0.5
      SIGYM=SIGMAY/(FN-1.0)**0.5
      DO 20 I=1,NTOTAL,NVAR
      JAY=I+KX
      KAY=I+KY
      IF(XY(JAY).EQ.0.0)GO TO 17
      YPR=A+B*0.434294*ALOG(XY(JAY))
      GO TO 19
   17 YPR=0.0
   19 SUM(6)=SUM(6)+YPR
      SUM(7)=SUM(7)+YPR**2
   20 SUM(8)=SUM(8)+(XY(KAY)-YPR)**2
      SIGYPR=(SUM(7)/FN-(SUM(6)/FN)**2)**0.5
      RXY=SIGYPR/SIGMAY
      SXY=(SUM(8)/(FN-1.0))**0.5
      WRITE(6,30)IX,IY
   30 FORMAT(1H1,34H CORRELATION OF LOG(X) VS. Y (LOG(,I3,4H)VS.,I3,1H),
     1//,18H Y = A + B(LOG(x)),//)
      WRITE(6,40)A,B,SIGMAX,SIGMAY,SIGXM,SIGYM,RXY,SXY
   40 FORMAT(4H A =,F10.4/4H B =,F10.4//24H STD. DEVIATION X DIR. =F10.4
     1/24H STD. DEVIATION Y DIR. =,F10.4//26H STD. ERROR OF MEAN OF X =,
     2F10.4/26H STD. ERROR OF MEAN OF Y =,F10.4//29H COEFFICIENT OF CORR
     3ELATION =,F10.4//25H STD. ERROR OF ESTIMATE =,F10.4)
      WRITE(6,250) NDATA
  250 FORMAT(1HO,20HNO. OF DATA PAIRS = ,I5)
      RETURN
      END
$IBFTC FIT4.
      SUBROUTINE FIT4(IX,IY)
      DIMENSION XY(20000),SUM(8)
      COMMON XY,NVAR,NTOTAL,NDATA
      DO 10 I=1,8
```

```
10 SUM(I)=0.0
   KX=IX-1
   KY=IY-1
   DO 15 I=1,NTOTAL,NVAR
   JAY=I+KX
   KAY=I+KY
   IF(XY(JAY).EQ.0.0)GO TO 15
   XL=0.434294*ALOG(XY(JAY))
   SUM(1)=SUM(1)+XL
   SUM(4)=SUM(4)+XL**2
15 CONTINUE
   DO 16 I=1,NTOTAL,NVAR
   KAY=I+KY
   JAY=I+KX
   IF(XY(KAY).EQ.0.0)GO TO 16
   YL=0.434294*ALOG(XY(KAY))
   SUM(2)=SUM(2)+YL
   SUM(5)=SUM(5)+YL**2
16 CONTINUE
   DO 17 I=1,NTOTAL,NVAR
   KAY=I+KY
   JAY=I+KX
   IF(XY(JAY).EQ.0.0.OR.XY(KAY).EQ.0.0)GO TO 17
   YL=0.434294*ALOG(XY(KAY))
   XL=0.434294*ALOG(XY(JAY))
   SUM(3)=SUM(3)+XL*YL
17 CONTINUE
   FN=NDATA
   B=(SUM(3)-SUM(1)*SUM(2)/FN)/(SUM(4)-SUM(1)**2/FN)
   A=SUM(2)/FN-B*SUM(1)/FN
   SIGMAX = (SUM(4)/FN -(SUM(1)/FN)**2 )**0.5
   SIGMAY = (SUM(5)/FN -(SUM(2)/FN)**2 )**0.5
   SIGXM=SIGMAX/(FN-1.0)**0.5
   SIGYM-SIGMAY/(FN-1.0)**0.5
   DO 20 I=1,NTOTAL,NVAR
   JAY=I+KX
   KAY=I+KY
   IF(XY(JAY).EQ.0.0)GO TO 18
   YPR=A+B*0.434294*ALOG(XY(JAY))
   GO to 19
18 YPR=0
19 SUM(6)=SUM(6)+YPR
   SUM(7)=SUM(7)+YPR**2
   IF(XY(KAY).EQ.0.0)GO TO 20
   SUM(8)=SUM(8)+(0.434294*ALOG(XY(KAY))-YPR)**2
20 CONTINUE
   SIGYPR=(SUM(7)/FN-(SUM(6)/FN)**2)**0.5
   RXY=SIGYPR/SIGMAY
   SXY=(SUM(8)/(FN-1.0))**0.5
   WRITE(6,30)IX,IY
30 FORMAT(1H1,39H CORRELATION OF LOG(Y) VS. LOG(X) (LOG(,I3,8H)VS.LOG
  1(,I3,1H),//,23H LOG(Y) = A + B(LOG(X)),//)
   WRITE(6,40)A,B,SIGMAX,SIGMAY,SIGXM,SIGYM,RXY,SXY
40 FORMAT(4H A =,F10.4/4H B =,F10.4//24G STD. DEVIATION X DIR. =F10.4
  1/24H STD. DEVIATION Y DIR. =,F10.4//26H STD. ERROR OF MEAN OF X =,
  2F10.4/26H STD. ERROR OF MEAN OF Y =,F10.4//29H COEFFICIENT OF CORR
```

```
     3ELATION = F10.4//25H STD. ERROR OF ESTIMATE =,F10.4)
      WRITE(6,250) NDATA
  250 FORMAT(1H0,20HNO. OF DATA PAIRS = ,I5)
      RETURN
      END
$DATA
```

```
$JOB           AB,2,1000      3GA81EC BUCHANAN, R. J.
$ID
$EXECUTE       IBJOB
$IBJOB
$IBFTC VAR-N
C   *******************************************************************
C       THIS PROGRAM IS DESIGNED TO COMPARE THE VALUES FOR WEIGHT TOTAL
C       SESTON DETERMINED FROM DUPLICATE FILTERS, ONE CALLED -SESTON-, AND
C       ONE CALLED -CARBON-, IN A LARGE NUMBER OF WATER SAMPLES.
C       A MEAN VALUE IS CALCULATED FOR EACH PAIR, AND THE DEVIATION FROM
C       THAT MEAN IS EXPRESSED AS A PERCENTAGE OF THE MEAN.
C       THE AVERAGE PERCENTAGE DEVIATION, THE STANDARD DEVIATION, AND THE
C       COEFFICIENT OF VARIATION ARE DETERMINED FOR ALL SETS OF DUPLICATES.
C                                         = =  R. J. BUCHANAN
C   *******************************************************************
      DIMENSION SAMPLE(194,2),SESTON(194),CARBON(194),MEANWT(194),PCTDEV
     1(194),SQPCDV(194)
      REAL MEANWT
      DO 20 I=1,194
      READ(5,10)(SAMPLE(I,J),J=1,2),SESTON(I),CARBON(I)
   10 FORMAT(2A6,2F6.2)
   20 CONTINUE
      SUMDEV=0.0
      SUMDSQ=0.0
      DO 30 I=1,194
      MEANWT(I)=(SESTON(I)+CARBON(I))/2.0
      PCTDEV(I)=(ABS(MEANWT(I)-SESTON(I))/MEANWT(I))*100.0
      SQPCDV(I)=PCTDEV(I)**2.0
      SUMDEV=SUMDEV+PCTDEV(I)
      SUMDSQ=SUMDSQ+SQPCDV(I)
   30 CONTINUE
      AVPCDV=SUMDEV/194.0
      STDDEV=SQRT((SUMDSQ/194.0)-AVPCDV**2.0)
      COEFDV=(STDDEV/AVPCDV)*100.0
      WRITE(6,40)
   40 FORMAT(1H1,68X,7HPERCENT)
      WRITE(6,50)
   50 FORMAT(1H ,30X,46HDRY WEIGHT  DRY WEIGHT    MEAN        DEVIATION)
      WRITE(6,60)
   60 FORMAT(1H ,10X,6HSAMPLE,15X,8H-SESTON-,4X,8H-CARBON-,2X,10HDRY WEI
     1GHT,4X,9HFROM MEAN,//)
      DO 80 I=1,194
      WRITE(6,70)((SAMPLE(I,J),J=1,2),SESTON(I),CARBON(I),MEANWT(I),
     1PCTDEV(I))
   70 FORMAT(1H ,10X,2A6,4F12.2)
   80 CONTINUE
      WRITE(6,90)AVPCDV
   90 FORMAT(1H0,18X,41HAVERAGE PERCENT DEVIATION FROM THE MEAN =,F6.2,
     19H PERCENT.)
      WRITE(6,100)STDDEV
  100 FORMAT(1H0,14X,45HSTANDARD DEVIATION OF THE PERCENT DEVIATION =,
     1F6.2,1H.)
      WRITE(6,110)COEFDV
  110 FORMAT(1H0,8X,51HCOEFFICIENT OF VARIATION OF THE PERCENT DEVIATION
     1 =,F6.2,9H PERCENT.)
      STOP
      END
```

APPENDIX B

MANUSCRIPT FOR PUBLICATION, DERIVED IN PART, FROM THE MOSES LAKE STUDY

INDICATOR PHYTOPLANKTON COMMUNITIES:
A CLUSTER ANALYSIS APPROACH [1,2]

by

R. J. Buchanan
Water and Air Resources Division
Department of Civil Engineering
University of Washington
Seattle, Washington 98105

and

Bruce Lighthart
Institute for Fresh Water Studies
Western Washington State College
Bellingham, Washington 98225

---

[1] Supported by the Federal Water Pollution Control Administration, through research grant WP-01391-01, and by the National Science Foundation, through research grant GK-1337, to the Department of Civil Engineering, University of Washington.

[2] Contribution No. 11 of the Institute for Fresh Water Studies, Western Washington State College, Bellingham, Washington 98225.

ABSTRACT

A new approach to the identification and application of biotic indicators of water quality is discussed. The key innovation is the application of numerical taxonomic techniques to pollution research and water quality management.

Numerical taxonomy has been employed: (1) to delineate objectively biotic regions on the basis of the planktonic biota present, and (2) to identify objectively species assemblages which are characteristic of various water parcels.

Examples of the application of selected methods to two different environments are discussed. The first, involving published data on phytoplankton of the Bahama Islands region, demonstrates the capacity of the methods to identify groupings of plankton and samples that could not be detected by conventional means. The second, involving a study of a eutrophic eastern Washington lake, demonstrates the regional and temporal distributions of community types, and identifies plankton groups which characterize these types.

Objectively identified assemblages of samples or organisms can be manipulated in a variety of ways. Their spatial and/or temporal distributions can be mapped, their existence can be examined for correlation with environmental events or parameters, or autecological studies can be conducted on diagnostic organisms to enable prediction of biota from environmental data (or vice versa).

With further development, the techniques are expected to enable the biota to be used as indicators of water quality on a more rigorously objective basis and with far greater sensitivity than was heretofore possible.

INTRODUCTION

Environmental quality is one of the most pressing problems of our time (Harrar, 1968). An important aspect of this complicated problem is the evaluation of water quality at any point in time and space, and further, the evaluation of perturbations therein.

Biological indicators of water history and quality have been under investigation for several decades, and have been extended to diverse groups of organisms. Marine zooplankton have been used to indicate water movements where other means were unsuccessful (Russell, 1935, 1939; Bary, 1959, 1964). Benthic marine and freshwater invertebrates have been widely correlated with habitat quality (Gaufin and Tarzwell, 1952; Reish, 1960; Warinner and Brehmer, 1965; Wass, 1967). Lackey (1957) and Lighthart (1969) have investigated protozoa as biological indicators. Marine phytoplankton (Wood, 1954) and seaweeds (Sundane, 1953), as well as freshwater diatoms (Patrick _et al_., 1954; Patrick and Strawbridge, 1963) and other freshwater algae (Kolkwitz, 1950; Liebmann, 1951; Palmer, 1957, 1962, 1969; Whipple, Fair and Whipple, 1948), have been used as indicators.

The application of indicator organisms to the problems of environmental quality control should embody the following desirable features, some of which are lacking in methods used in the past:

(1) The temporal and spatial patterns of the flora and fauna should be known _before_ perturbations occur.

(2) The method should be sensitive enough to detect changes in the early stages.

(3) The method should employ many kinds of organisms.

(4) The specific tolerances of the organisms should be known.

(5) The correlations between organisms and environmental factors should be objective.

(6) The monitoring procedure should be simple and rapid.

While the various indices of diversity which have been developed in recent years do yield valuable data, they suffer from serious deficiencies. There is some doubt about the underlying theory of their meaning and use, and they require (1) an expert to interpret, (2) accurate identification of organisms (to enable comparison of different communities), and (3) enumeration of the different organisms. Consequently, such indices are presently not well suited to use by monitoring personnel.

The underlying theory for the type of community structure analysis we advocate suffers from some uncertainties. However, when it is fully developed, assessment of environmental quality or the detection of perturbations therein would require only the collection of water samples and qualitative analysis of the planktonic organisms, once the norms for any particular location and time have been established.

Our procedure makes use of numerical taxonomy, a powerful tool for drawing together large amounts of diverse data into more easily interpretable form. Numerical taxonomy compares a large number of items with respect to a large number of characteristics, and determines an index of similarity for all possible pairs of items. The items are then clustered into groups with mutually high indices (i.e., with high overall character similarity) in an objective and repeatable manner. The reader is referred to Sokal and Sneath (1963) for a complete account of the procedures. The clusters can then be examined for correlation with other factors. The demonstrated correlations can be ecologically significant or merely have predictive value. In either case, the method can be valuable in generating testable hypotheses.

This report presents the results of preliminary work on the application of numerical taxonomy and the indicator species concept to water quality assessment.

METHODS

To establish the identity of recurrent species assemblages or communities, it is desirable to have samples which allow quantitative analyses so that the presence or absence of species can be determined objectively at uniform abundance levels. For numerico-taxonomic analysis, the occurrence of each species is recorded on computer cards for each sample. The computer is programmed to compute indices of similarity in two ways: (1) for all possible pairs of species on the basis of the samples they occurred in, and (2) for all possible pairs of samples on the basis of the species which were present. The arrays of species and samples are rearranged by a clustering program on the basis of the highest mean value for the similarity indices of the resulting clusters. This yields groupings of species and samples which have mutually high similarity indices. The index used in this case was that of Fager (1963).

The groups of species are taken to represent recurrent assemblages of organisms which can be mapped spatially or temporally, correlated with environmental factors, or otherwise treated. The groups of samples represent biologically similar locations which can be mapped to delineate biotic regions in time or space, or subjected to correlation analyses as with species groups.

As a test of the methods outlined above, data on the occurrence of 90 species in 32 samples from four stations were taken from Wood (1968). In his study of the planktonic biota of the Bahama Islands region, Wood was unable to identify any strong spatial or temporal patterns. This is probably due to the great subtlety of differences, a situation ideal for testing the power of our method.

Our lake plankton collections consisted of 86 integrated samples pumped continuously from 40 cm depth along transects in eight morphometrically distinct segments of Moses Lake, Washington (Figure 1). Collections were made periodically from July to December, 1968. Samples could be point samples collected in a three-dimensional array if desired.

One milliliter aliquots of the preserved samples were examined with a compound microscope and each species present in excess of a uniform concentration limit was tabulated for each sample. The limit can be chosen so that only the most abundant species are recorded, or so that virtually all species are recorded. In our case, the limit was set at equal to or greater than five cells per milliliter. This caused exclusion of from 12.5% to 54.2% of all taxa detected in one milliliter aliquots (the average being 32.8%).

RESULTS AND DISCUSSION

The results of our treatment of Wood's (1968) plankton data are illustrated in Figures 2 and 3. Figure 2 shows the eleven major species groups identified. The inter-group similarities are summarized in Table I. The seven sample groups we identified are shown in Figure 3, and their inter-group similarities are summarized in Table II.

The comparable Moses Lake results are shown in Figures 4 and 5. There are five distinguishable major species groups (Figure 4) of which three (1, 2, 4) can be subdivided. We recognize seven sample groups (Figure 5) three of which (1, 2, 5) can be subdivided. The inter-group similarities are summarized in Tables V and VI.

All these groupings will be discussed at length below.

BAHAMA ISLANDS SPECIES GROUPS

Among these groups (Figure 2, Table I) group 3 is nearly ubiquitous, having a fairly high joint occurrence frequency with all other groups. It therefore cannot be used in characterizing water bodies in this case. Group 4 apparently has a higher inter-group similarity with Group 3 than its intragroup similarity. The members of Group 4 are less frequent in occurrence than those of Group 3 and more commonly occur with members of Group 3 than with each other, so their inter-group indices are consequently relatively high. Group 5 also displays this close relationship with both groups 3 and 4. Members of Group 5 seem to have high joint occurrence frequencies with Groups 3 and 4 but not with each other. most useful species groups for diagnostic purposes would be Groups 1, 2, and 6 to 11 because of their tendency to be mutually exclusive. Group 6, having some similarity to several other groups, might be found in mixed waters or in transition periods during succession, where more than one type of flora are intermingled. This is supported by the sample groupings discussed below.

Inspection of the original occurrence data revealed that the Bahamas species groups were a reflection mainly of temporal periodicity in species occurrence.

BAHAMA ISLANDS SAMPLE GROUPS

Inspection of the occurrence data showed that these seven clusters (Figure 3) fell into the three categories listed in Table III. When these groups are tabulated according to their geographic locations for each sampling occasion (Table IV) it is quite easy to visualize the sequence of events. From October, 1964 to April, 1965, no significant changes occurred. Between April and July, 1965, Northwest Providence Channel became variable, and remained so until

August, 1966; all other stations remained virtually unchanged. Between July and October, 1965, the differences between the Atlantic Ocean and Northeast Providence Channel disappeared, the floras becoming intermediate between the two earlier types (probably due to mixing) and moderately similar to the Tongue of the Ocean (probably due to the fact that the latter station's flora is a mixture including the Atlantic Ocean, Northeast Providence Channel, and the flora typical of Tongue of the Ocean). Between October, 1965 and January, 1966, Tongue of the Ocean became distinct from the Northeast Providence Channel - Atlantic Ocean mixed flora through the removal of Atlantic Ocean species. From January to April, 1966, the floristic distribution remained unchanged. Between April and August, 1966, Northeast Providence Channel changed to a typically Atlantic Ocean flora while the Atlantic Ocean station remained unchanged. It is difficult to explain an intrusion of Atlantic Ocean water into the Northeast Providence Channel zone while the Atlantic Ocean station retained the mixed flora, but such is suggested by our analyses.

The highly variable nature of Group 7, found in Northwest Providence Channel from July, 1965 to August, 1966, is demonstrated by the lack of strong similarity between successive sampling times. This indicates that there is no persistent influence by another water body such as the Florida Current or Tongue of the Ocean. That station tends to have fewer species which occur repeatedly and is highly variable compared with the other three stations. Furthermore, Northwest Providence Channel does not experience notable cyclic variation as occurs at other stations.

MOSES LAKE SPECIES GROUPS

The most ubiquitous group of species in Moses Lake (Figure 4, Table V) is Group 2, which is quite common at all transects sampled. These species, therefore do not lend themselves to distinguishing regions of Moses Lake. Similarly, but to a lesser extent, Group 3 is widespread and without strong seasonal distribution. Group 1A includes organisms characteristically found only in Transect J, Group 1B mainly in transects J and K, Group 4 only in transects A and B, and Group 5 only in transect K. Thus, the species groups in Moses Lake reflect mostly spatial distributions rather than temporal periodicity as in the Bahama Islands data.

MOSES LAKE SAMPLE GROUPS

Moses Lake samples fell into seven major groups (Figure 5, Table VI) mainly reflecting geographic position; three of the seven can be subdivided, the subdivisions reflecting a combination of temporal and spatial differences. Figures 6 and 7 are examples of spatial maps of sample groups for October 25, 1968 and December 13, 1968, respectively. Table VII summarizes the temporal versus spatial distribution of the sample groups and subgroups. The dominance of spatial influence on groups is shown in this table by the prevalence of vertical lines separating the major groups; subgroups are separated more by horizontal, but some vertical, dashed lines, indicating stronger temporal influence at that level of similarity.

Table VI indicates no similarity between either subgroup 5B or 2A and Group 6, but a high similarity between Groups 4 and 6. The distribution of these groups in Table VII indicates that as the autumn progressed, transect C changed from a flora very unlike transects A and B to one somewhat like A and B, and finally, in December, to one identical to A and B. Thus, the sample groups show the progressive influence of the creek inflow above transect A upon one arm of Moses Lake.

A similar type of temporal progression can be seen in transects J and K (Table VII). As the autumn progressed, the flora changed from subgroup 5B to subgroup 5C, which has very high similarity to 5B. After October 11, the main lake level was lowered, so that K was higher than J, enabling isolation of K from J but permitting K to influence J by outflow. Transect K quickly changed to Group 3, which has high similarity to subgroup 5C but low similarity to subgroup 5B. Eventually the outflow from K to J changed the flora of J to that established earlier in K (Group 3).

CONCLUSION

Our analysis of extremely confusing data from the Caribbean area has established the ability of our procedure to elucidate subtle differences in community structure.

The clusters of species or samples do not necessarily reflect the same forces on different occasions, as is shown by Bahama Islands results reflecting temporal changes while Moses Lake results reflected spatial changes.

Our results indicate that our methods can be valuable in early detection of environmental changes so that early corrective measures can be applied, while costs are lower and undesirable developments are reversible. When data from widely distributed samples, in time and space, have been amassed and analysed by the foregoing techniques and newer modifications and refinements, it will be possible to prepare summaries of water biota distribution analogous to weather charts. Once norms have been identified, continued sampling and analysis will enable the detection of anomalies, evaluation of their causes and seriousness and, ultimately, the planning of early corrective measures when they are warranted.

REFERENCES

Bary, B. M. 1959. Species of zooplankton as a means of identifying different surface waters and demonstrating their movements and mixing. Pacific Science, 13:14-54.

Bary, B. M. 1964. Temperature, salinity and plankton in the eastern North Atlantic and coastal waters of Britain, 1957. IV. The species' relationship to the water body; its role in distribution and in selecting and using indicator species. J. Fish. Res. Bd. Canada, 21:183-202.

Fager, E. W. 1963. Communities of organisms. Pp. 415-437. In M. N. Hill (ed.), The sea, ideas and observations on progress in the study of the sea, Vol. 2. The composition of sea-water, comparative and descriptive oceanography. Interscience Publishers, New York. 3 vols.

Gaufin, A. R. and C. M. Tarzwell. 1952. Aquatic invertebrates as indicators of stream pollution. U.S. Public Health Report, 67:57-64.

Harrar, J. G. 1962. Crisis in human ecology. Proc. Nat. Acad. Sci., 61:357-362.

Kolkwitz, R. 1950. Oekologie der Saprobian. Ueber die Bezeihungen der Wasserorganisman zur Umwelt. Schriftenreiche des Vereins fur Wasser-, Boden-, und Lufthygiene, No. 4. 64 pp.

Lackey, J. B. 1957. Protozoa as indicators of the biological condition of a body of water. Pp. 50-59. In C. M. Tarzwell (ed.). Biological problems in water pollution. U. S. Public Health Serv., Robert A. Taft Sanitary Engr. Center, Cincinnati, Ohio.

Leibmann, H. 1951. Handbuch der Frishwasser-, und Abwasserbiologie. Bd. 1. R. Oldenbourg, Munchen, Germany. 539 pp.

Lighthart, Bruce. 1969. Planktonic and benthic bacteriovorous protozoa at eleven stations in Puget Sound and adjacent Pacific Ocean. J. Fish. Res. Bd. Canada, 26:299-304.

Palmer, C. M. 1957. Algae as biological indicators of pollution. Pp. 60-69. In C. M. Tarzwell (ed.). Biological problems in water pollution. U. S. Public Health Serv., Robert A. Taft Sanitary Engr. Center, Cincinnati, Ohio.

Palmer, C. M. 1962. Algae in water supplies. U. S. Public Health Serv., Robert A. Taft Sanitary Engr. Center, Cincinnati, Ohio. Publ. No. 657, 88 pp.

Palmer, C. Mervin. 1969. A composite rating of algae tolerating organic pollution. J. Phycol., 5:78-82.

Patrick, Ruth, M. H. Hohn, and J. H. Wallace. 1954. A new method for determining the pattern of the diatom flora. Nodulae Naturae, Acad. Natural Sci., Philadelphia. No. 259. 12 pp.

Patrick, R. and D. Strawbridge. 1963. Methods for studying diatom populations. J. Water Pollution Control Federation, 35:151-161.

Reish, D. J. 1960. The uses of marine invertebrates as indicators of water quality. Pp. 92-103. in E. A. Pearson (ed.). Waste disposal in the marine environment. Proc. 1st Intern. Conf. Pergamon Press, New York. 569 pp.

Russell, F. S. 1935. On the value of certain plankton animals as indicators of water movement in the English Channel and North Sea. J. Mar. Biol. Assoc. U. K., 20:309-332.

Russell, F. S. 1939. Hydrographical and biological conditions in the North Sea as indicated by plankton organisms. Cons. Perm. Internat. Explor. Mer., J. du Conseil, 14: 171-192.

Sokal, R. R. and P. H. A. Sneath. 1963. Principles of numerical taxonomy. W. H. Freeman & Co., San Francisco and London. 359 pp.

Sundane, O. 1953. The algal vegetation of Oslo Fjord. Skr. Norsk Vidensk.-Acad. Norway, No. 2. 244 pp.

Warinner, J. E. and M. L. Brehner. 1965. The effects of thermal effluents on marine organisms. Industrial Waste Conference, Proc. 19th Purdue Univ., Eng. Ext. Ser. 117, pp. 479-492.

Wass, M. L. 1967. Biological and physiological basis of indicator organisms and communities. Section II. Indicators of pollution. Pp. 271-283. In Theodore A. Olsen and Fredrick L. Burgess (eds.). Pollution and Marine Ecology. Interscience Publishers, New York. 364 pp.

Whipple, G. C., G. M. Fair, and M. C. Whipple. 1948. The microscopy of drinking water. Ed. 4. J. Wiley & Sons, New York. 586 pp. + 19 pl.

Wood, E. J. F. 1954. Dinoflagellates in the Australian region. Aust. J. Mar. Freshwater Res., 5:171-351.

Wood, E. J. F. 1968. Studies of phytoplankton ecology in tropical and subtropical environments of the Atlantic Ocean. Part 3. Phytoplankton communities in the Providence Channels and Tongue of the Ocean. Bull. Mar. Sci., 18:481-543.

Table I. Intergroup distribution similarities for species groups of the Bahama Islands region (original data were taken from Wood, 1968).

Species Groups	1	2	3	4	5	6	7	8	9	10	11
1											
2	**										
3	**	***									
4	***	**	***								
5	**	*	***	***							
6		**	***	***	*						
7	*		**	*							
8			**								
9			**				**				
10			*				*				
11			**				*				

Species Groups

Legend

*** = very high similarity
** = high similarity
* = low similarity

TABLE II. Intergroup biotic similarities for sample groups of the Bahama Islands region (original data were taken from Wood, 1968).

Sample Groups	1	2	3	4	5	6	7
1							
2	***						
3	**	***					
4		*					
5		*	*	*			
6	*	**	*	*	**		
7							

Sample Groups

Legend

*** = very high similarity
** = high similarity
* = low similarity

Table III. Floristic types found among the 32 samples from the Bahama Islands region (original data were taken from Wood, 1968).

Basically Unique Floras:

Group	Typical of:
1	N. E. Providence Channel (uniform)
3	Atlantic Ocean (uniform)
4	N. W. Providence Channel (moderately variable)
5	Tongue of the Ocean (uniform, some attributes of 1 and 3)

Mixtures of Basically Unique Floras:

Group	Mixture of:
2	1 + 3
6	1 + 3 + 5*

Strongly Variable But Distinct From All Other Floras:

Group 7

---

* Group 5 apparently is the dominant fraction of Group 6, since 6 is more similar to 5 than to 1 or 3 (Table II).

TABLE IV. Spatial and temporal distribution of the floristic types found in Wood's (1968) data from the Bahama Islands region.

DATE	Northwest Providence Channel	Tongue of the Ocean	Northeast Providence Channel	Atlantic Ocean
Oct. 1964	4	6**	1	3
Jan. 1965	4	6**	1	3
Apr. 1965	4	6**	1	3
July 1965	7	6**	1	3
Oct. 1965	7	6**	2*	2*
Jan. 1966	7	5	2*	2*
Apr. 1966	7	5	2*	2*
Aug. 1966	7	5	3	2*

* Mixture of floristic types 1 and 3 (cf. Table III).

** Mixture of floristic types 1, 3 and 5 (cf. Table III).

TABLE V. Intergroup distribution similarities for species groups of Moses Lake, Washington.

Species Groups	1A	1B	2A	2B	3	4A	4B	5
1A								
1B	*							
2A		**						
2B		**	***					
3		*	***	**				
4A			**	**				
4B						*		
5								

Legend

*** = very high similarity
** = high similarity
* = low similarity

TABLE VI. Intergroup biotic similarities for sample groups of Moses Lake, Washington.

Sample Groups	1A	1B	2A	2B	3	4	5A	5B	5C	6	7
1A											
1B	**										
2A		**									
2B		**	**								
3				*							
4		*									
5A			*	*							
5B		*	*	*			**				
5C							*	***			
6						**					
7											

Sample Groups

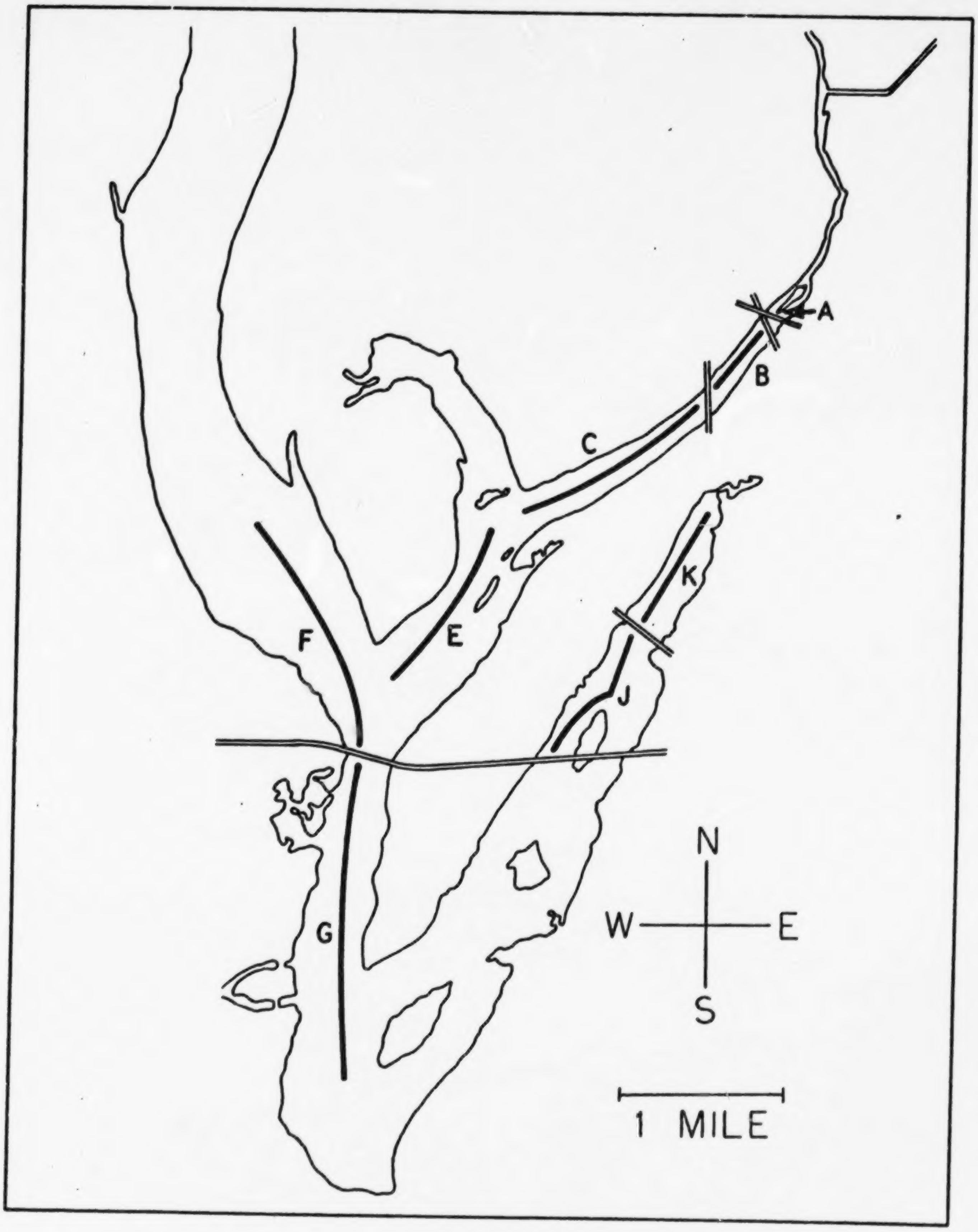
*** = very high similarity
** = high similarity
* = low similarity

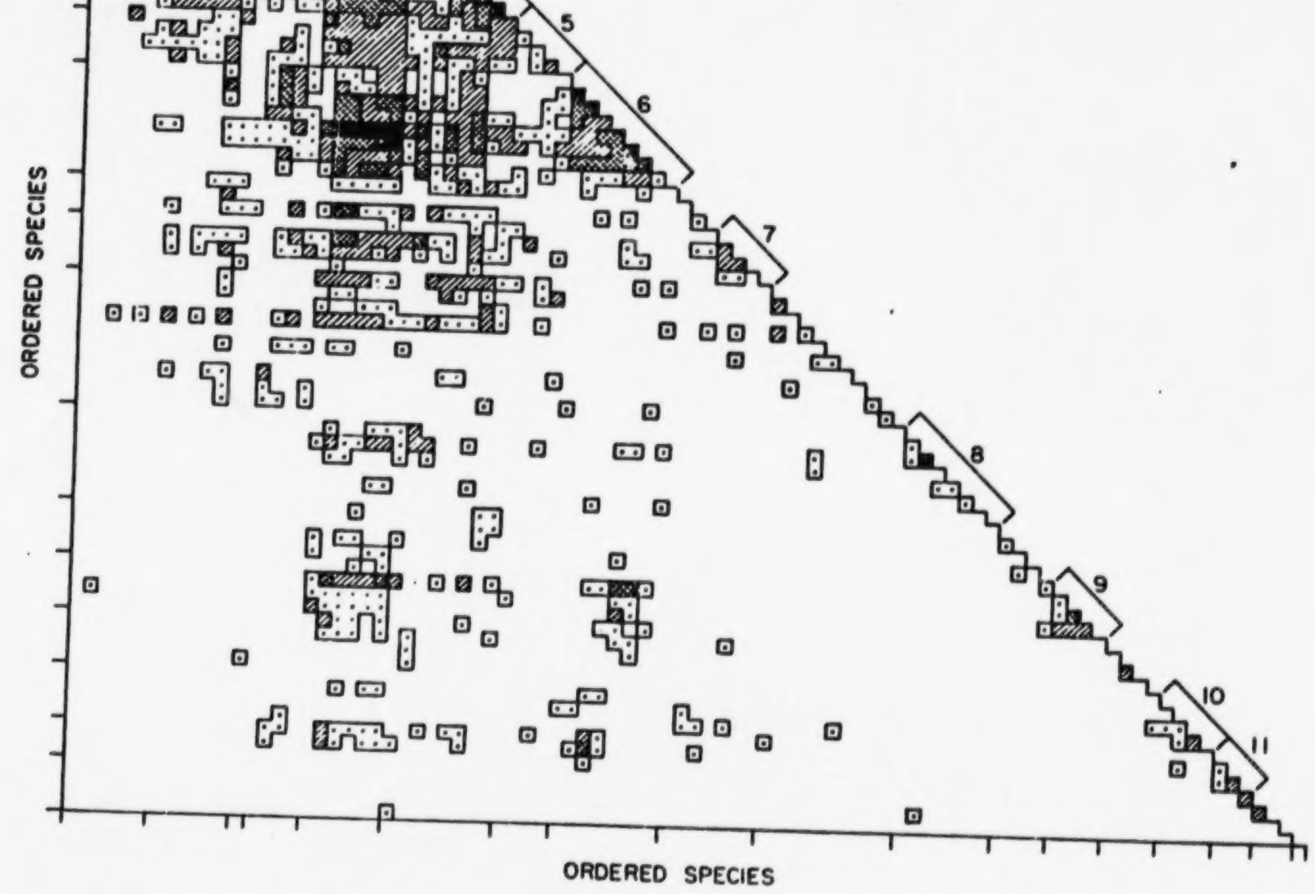
TABLE VII. Spatial and temporal distribution of the groups and subgroups of samples in Moses Lake, Washington.

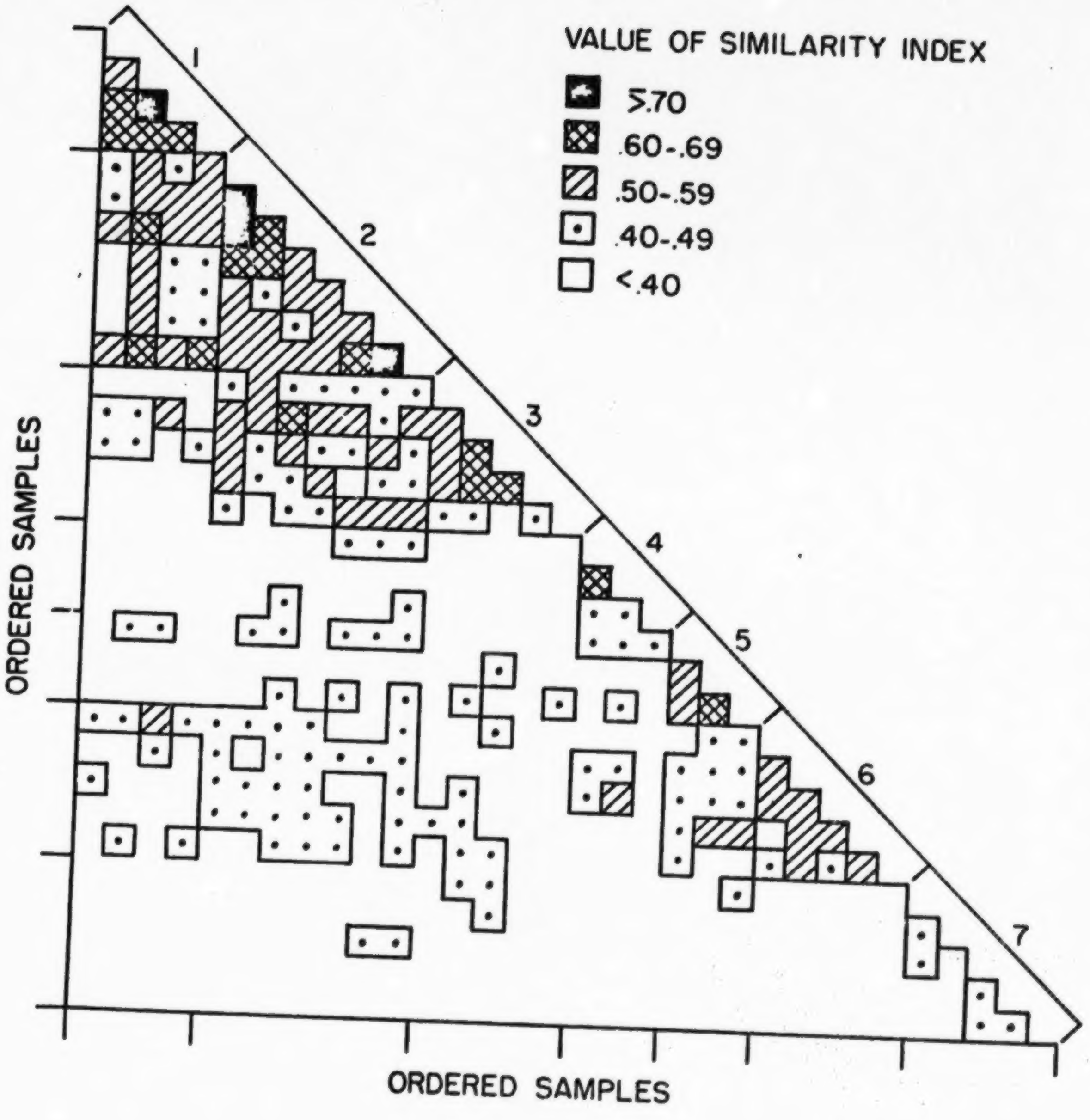
DATES	TRANSECTS							
	A	B	C	E	F	G	J	K
July 30, 1968	6		5A	5A				
Aug. 9, 1968	6	6	5B	2B	5A	2A	5B	5B
Aug. 16, 1968	6	6	2A	2A	2A	2A	5B	5B
Aug. 23, 1968	6	6	2A	2B	7	2A	5B	5B
Aug. 30, 1968	6	6	2A	2B	2B	2B	5B	5B
Sept. 17, 1968	6	6	2A	2B	2B	2B	5C	5C
Sept. 24, 1968	6	6	4	2B	2A	2B	5C	5C
Oct. 11, 1968	6	6	4	1B	1B	1B	5C	5C
Oct. 25, 1968	6	6	4	1B	1B	1B	5C	3
Nov. 8, 1968	6	6	4	1B	1B	1B	5C	3
Nov. 22, 1968	6	6	4					3
Dec. 13, 1968	6	6	6	1A	1A	1A	3	3

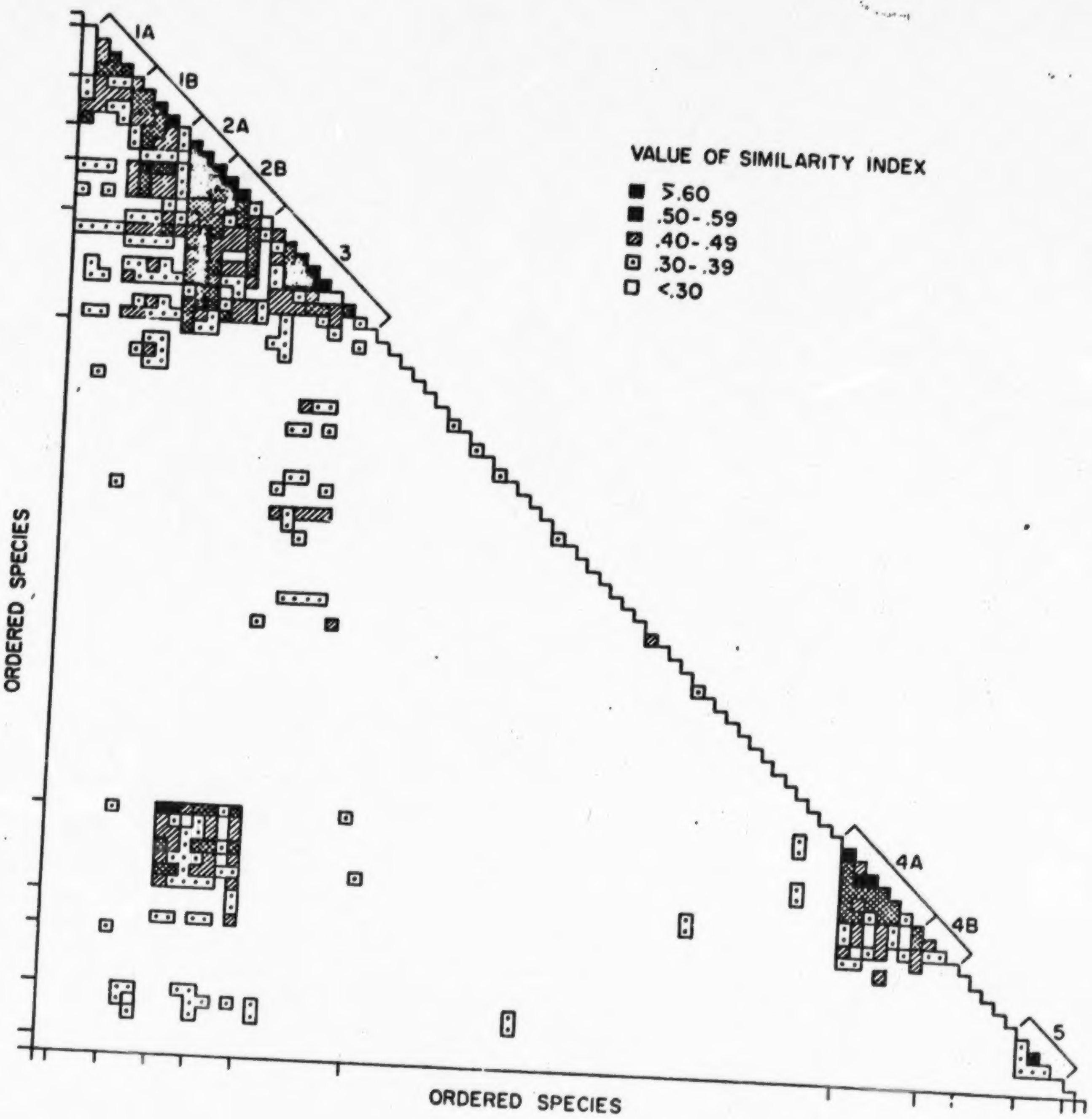
FIGURE LEGENDS

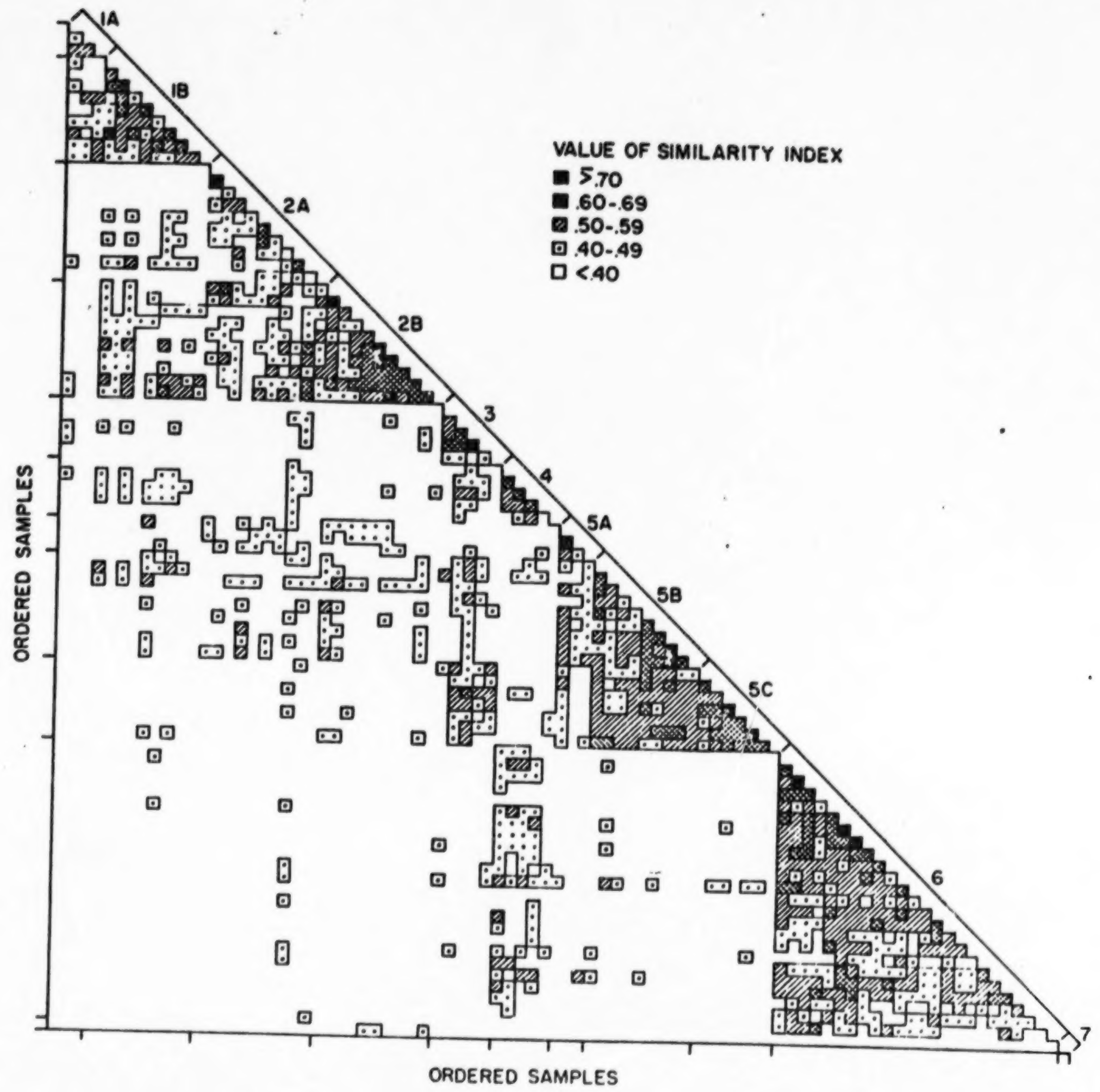
1. Plan of Moses Lake, Washington, showing the locations of sampling transects used to collect integrated samples.
2. Clustered species from the Bahama Islands region, showing the 11 recognizable groups based on their mean similarity indices (original data were taken from Wood, 1968).
3. Clustered samples from the Bahama Islands region, showing the seven recognizable groups based on their mean similarity indices (original data were taken from Wood, 1968).
4. Clustered species from Moses Lake, Washington, showing the five recognizable groups based on their mean similarity indices, and the two subgroups recognizable in groups 1, 2, and 4.
5. Clustered samples from Moses Lake, Washington, showing the seven recognizable groups based on their mean similarity indices, and the subgroups recognizable in groups 1, 2, and 5.
6. Plan of Moses Lake, Washington, showing the distribution of sample groups (floras) on October 25, 1968.
7. Plan of Moses Lake, Washington, showing the distribution of sample groups (floras) on December 14, 1968.

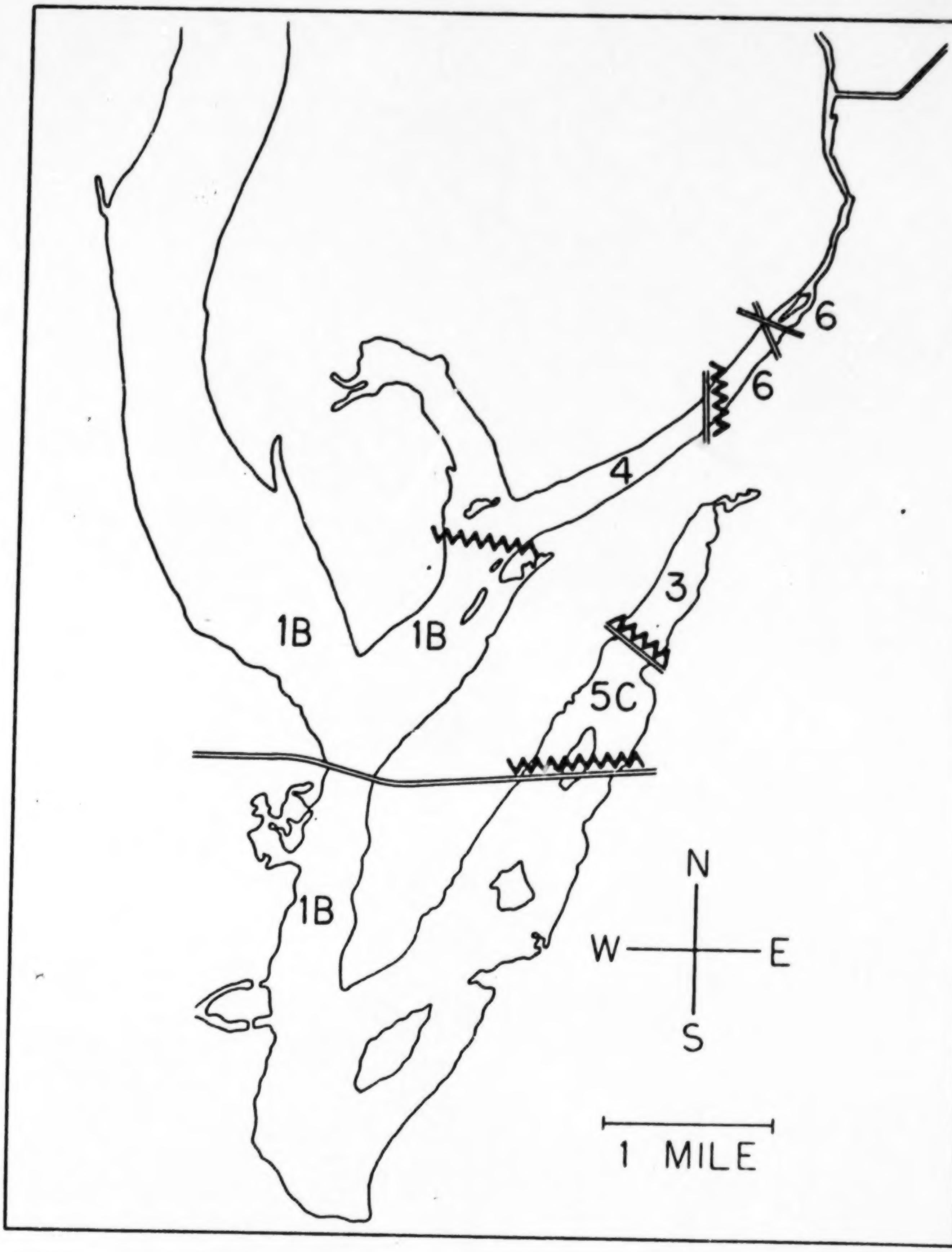

A
B
C
E
F
G
J
K
N
W
E
S
1 MILE

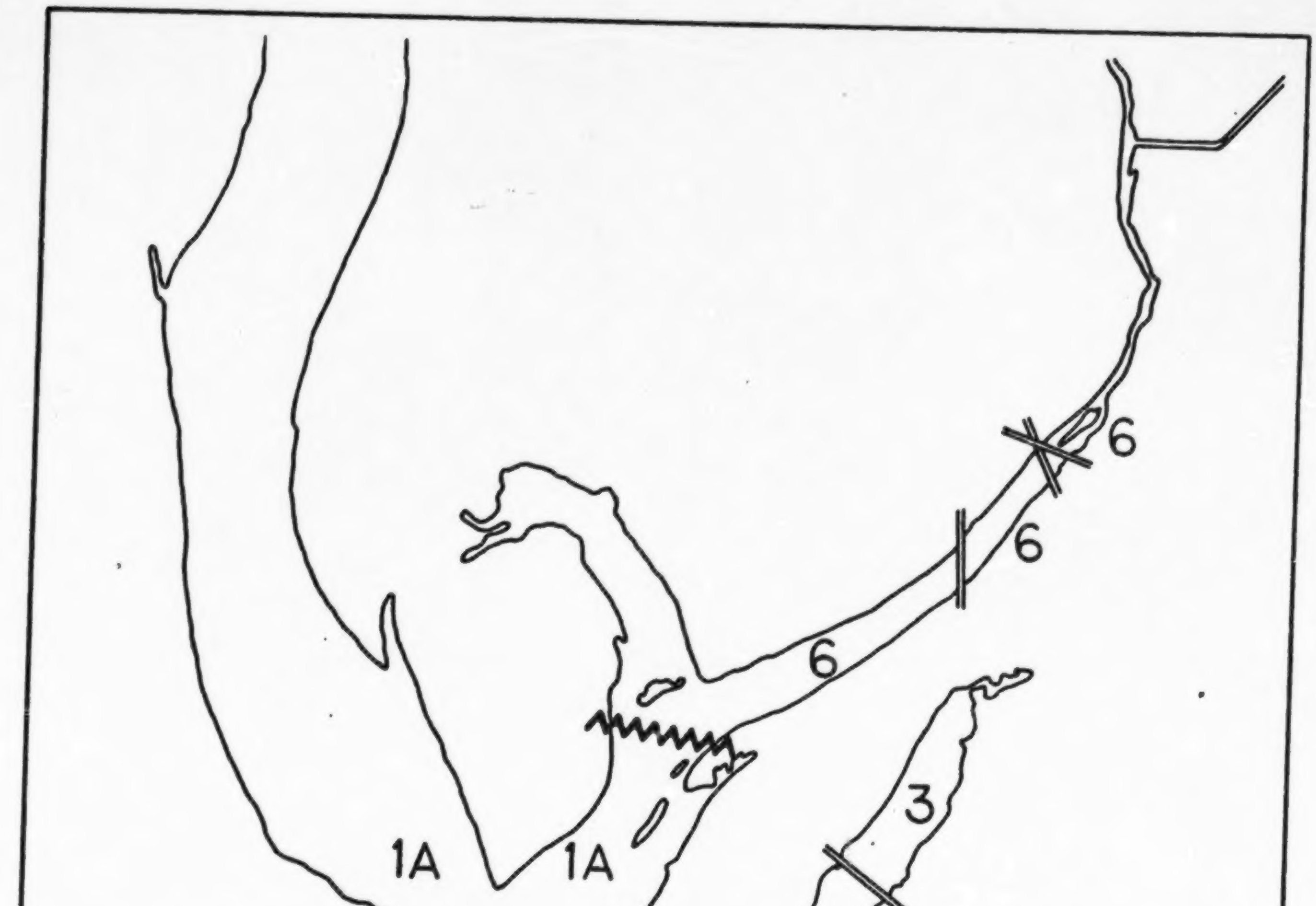

VALUE OF SIMILARITY INDEX
■ ≥.70
■ .60-.69
▨ .50-.59
⊡ 40-.49
□ <.40
1
2
3
4
5
6
7
8
9
10
11
ORDERED SPECIES
ORDERED SPECIES


VALUE OF SIMILARITY INDEX
≥.70
.60-.69
.50-.59
.40-.49
<.40
1
2
3
4
5
6
7
ORDERED SAMPLES
ORDERED SAMPLES


1A
1B
2A
2B
3
VALUE OF SIMILARITY INDEX
■ ≥.60
■ .50-.59
▨ .40-.49
⊡ .30-.39
□ <.30
ORDERED SPECIES
4A
4B
5
ORDERED SPECIES


1A
1B
2A
2B
3
4
5A
5B
5C
6
7
VALUE OF SIMILARITY INDEX
■ ≥.70
■ .60-.69
▨ .50-.59
⊡ .40-.49
□ <.40
ORDERED SAMPLES
ORDERED SAMPLES


6
6
4
1B
1B
3
5C
1B
N
W
E
S
1 MILE


6
6
6
3
3
1A
1A
1A
N
W
E
S
1 MILE

APPENDIX C

TAXONOMIC NOTES ON ALGAE AND PROTOZOA FROM MOSES LAKE

ALGAE AND PROTOZOA FROM MOSES LAKE PLANKTON

The following is a complete list of the microorganisms identified in the plankton of Moses Lake during the period July 1968 to May 1969. The references cited under each taxon are not meant to be a complete list, but some of those which contain illustrations of the taxon concerned, to aid the reader in ascertaining what organism is referred to.

CHLOROPHYCEAE

1. *Acanthosphaera zachariasi* Lemmermann.

   Smith (1950), p. 234, fig. 146; Prescott (1951), p. 212, pl. 45, figs. 4,5; Thompson (1959), p. 132, fig. 6.101.
2. *Actinastrum* cf. *gracillimum* G. M. Smith.

   Smith (1950), p. 276, fig. 197B,C; Prescott (1951), p. 281, pl. 64, fig. 5; Thompson (1959), p. 138, fig. 6.184; Palmer (1962), pl. 5.

   In some cases more likely to be *A. hantzschii* Lagerheim because the cells were frequently quite tapered at both ends like *A. hantzschii* var. *fluviatile* Schroeder (Prescott, 1951, p. 282, pl. 65, fig. 1; Silva and Papenfuss, 1953, p. 16, fig. 19; Smith, 1951, p. 276, fig. 197A; Fritsch, 1935, p. 164, fig. 46J; Skuja, 1956, p. 181, pl. 29, fig. 5-8).
3. *Ankistrodesmus falcatus* (Corda) Ralfs.

   Fritsch (1935), p. 164, fig. 46G; Smith (1950), p. 264, fig. 180; Silva and Papenfuss (1953), p. 17, fig. 28; Thompson (1959), p. 136, fig. 6.148; Palmer (1962), p. 44, fig. 35.
4. *Chodatella longiseta* Lemmerman.

   Smith (1950), p. 262, fig. 177G; Prescott (1951), p. 250, pl. 55, fig. 5 (Under *Lagerheimia longiseta* (Lemmermann) Printz).
5. *Chodatella subsalsa* Lemmermann.

   Smith (1950), p. 262, fig. 177E, F; Prescott (1951), p. 251, pl. 55, fig. 7 (Under *Lagerheimia subsalsa* Lemmermann).
6. *Closteriopsis longissima* Lemmermann.

   Smith (1950), p. 266, fig. 182; Prescott (1951), p. 255, pl. 57, fig. 1-3; Thompson (1959), p. 136, fig. 6.149.

   This organism was frequently not straight, but curved or helically bent.
7. *Closterium* cf. *acerosum* (Schrank) Ehrenberg.

   Fritsch (1935), p. 346, fig. 109M; Smith (1950), p. 317, fig. 226A.
8. *Closterium* cf. *polystictum* Nygaard.

   Skuja (1948), p. 153, pl. 18, fig. 1-3.
9. *Coelastrum sphaericum* Naegli.

   Fritsch (1935), p. 177, fig. 52A; Prescott (1951), p. 231, pl. 53, fig. 7; Thompson (1959), p. 134, fig. 6.122.
10. *Cosmarium* cf. *bioculatum* Brébisson.

    Smith (1950), p. 323, fig. 324A.
11. *Cosmarium* cf. *protractum* (Naegli) De By.

    Smith (1950), p. 323, fig. 234D.
12. *Cosmarium punctulatum* Brébisson.

    Smith (1950), p. 323, fig. 234E.
13. *Crucigenia quadrata* Morren.

    Smith (1950), p. 273, fig. 193C-D; Prescott (1951), p. 285, pl. 65, fig. 10.
14. *Crucigenia rectangularis* (A. Braun) Gay.

    Smith (1950), p. 273, fig. 193A (Under *C. rectangularis* (Naegli) Gay); Prescott (1951), p. 285, pl. 65, figs. 7, 8.
15. *Crucigenia tetrapedia* (Kirchner) W. West and G. S. West.

    Fritsch (1935), p. 175, fig. 51B; Skuja (1948), p. 140, pl. 16, fig. 7; Smith (1950), p. 273, fig. 193B; Prescott (1951), p. 285, pl. 65, fig. 9, pl. 66, fig. 1.
16. *Dictyosphaerium* cf. *pulchellum* Wood.

    Fritsch (1935), p. 165, fig. 47A-D; Smith (1950), p. 237, fig. 149; Prescott (1951), p. 238, pl. 51; figs. 5-7.

17. *Dimorphococcus* sp.
Fritsch (1935), p. 165, fig. 47G,H; Smith (1950), p. 237, fig. 150; Prescott (1951), p. 252, pl. 55, fig. 8; Thompson (1959), p. 134, fig. 6.114.

18. *Echinosphaerella limnetica* G. M. Smith.
Smith (1950), p. 257, fig. 170; Prescott (1951), p. 241, pl. 51, figs. 1,2; Thompson (1959), p. 136, fig. 6.135.

19. *Elakatothrix gelatinosa* Wille.
Fritsch (1935), p. 127, fig. 33D,F; Skuja (1948), p. 145, pl. 17, figs. 1,2; Smith (1950), p. 134, fig. 73A-B; Prescott (1951), p. 93, pl. 3, figs. 13, 14.
Possibly *E. viridis* (Snow Printz (Most likely, in fact except for the fact that cells were arranged like *E. gelatinosa* pairs). Prescott (1951), p. 93, pl. 4, figs. 1,2; Skuja (1948), p. 145, pl. 16, fig. 21; Smith (1950), p. 134, fig. 73C-F; Thompson (1959), p. 132, fig. 6.94.

20. *Franceia* cf. *droescheri* (Lemmermann) G. M. Smith.
Smith (1950), p. 263, fig. 178C-D; Prescott (1951), p. 251, pl. 56, fig. 1-3.

21. *Micractinium* cf. *pusillum* Fresenius.
Smith (1950), p. 234, fig. 147; Prescott (1951), p. 287, pl. 66, fig. 7,8; Silva and Papenfuss (1953), p. 15, fig. 15; Thompson (1959), p. 135, fig. 6.109; Palmer (1962), pl. 5.

22. *Oocystis lacustris* Chodat.
Smith (1950), p. 259, fig. 173E; Prescott (1951), p. 245, pl. 54, fig. 1; Skuja (1956), p. 172, pl. 27, fig. 8-12.

23. *Pandorina morum* (Mueller) Bory.
Fritsch (1935), p. 98, fig. 18H-K; Skuja (1948), p. 98; Smith (1950), p. 96, fig. 41 (Under *P. morum* Bory); Prescott (1951), p. 75, pl. 1, fig. 23; Skuja (1956), p. 155; Palmer (1962), pl. 1.

24. *Pediastrum boryanum* (Turpin) Meneghini.
Fritsch (1935), p. 168, fig. 48D, H, J; Skuja (1948), p. 127; Smith (1950), p. 243, fig. 155A; Prescott (1951), p. 222, pl. 47, fig. 9, 10, pl. 48, fig. 1-3; Skuja (1956), p. 167; Thompson (1959), p. 135, fig. 6.119; Palmer (1962), p. 9, fig. 6, pl. 5.

25. *Pediastrum duplex* Meyen.
Fritsch (1935), p. 168, fig. 48F, fig. 48G (Under *P. clathratum* (Schroeter) Lemmermann); Skuja (1948), p. 126; Prescott (1951), p. 223, pl. 48, fig. 4, 6-8, 11, 12, pl. 49, fig. 1, 3; Thompson (1959), p. 135, fig. 6.125; Palmer (1962), p. 57, fig. 51.

26. *Pediastrum simplex* (Meyen) Lemmermann.
Smith (1950), p. 243, fig. 155e; Prescott (1951), p. 227, pl. 50, fig. 2.

27. *Pediastrum tetras* (Ehrenberg) Ralfs.
Fritsch (1935), p. 168, fig. 481; Prescott (1951), p. 227, pl. 50, fig. 3, 6, 7.

28. *Scenedesmus acuminatus* (Lagerheim) Chodat.
Fritsch (1935), p. 175, fig. 51D, I; Prescott (1951), p. 275, pl. 62, fig. 16.

29. *Scenedesmus bijuga* (Turpin) Lagerheim.
Smith (1950), p. 272, fig. 191C; Prescott (1951), p. 276, pl. 63, fig. 2-4,7; Silva and Papenfuss (1953), p. 16, fig. 17.

30. *Scenedesmus quadricauda* Turpin em. Chodat.
Fritsch (1935), p. 175, fig. 51C,G,H,M (Under *S. quadricauda* (Turpin) Brébisson); Smith (1950), p. 272, fig. 191H; Prescott (1951), p. 280, pl. 63, fig. 21, 22, pl. 64, fig. 2-4,6,7,9; Palmer (1962), pl. 5.

31. *Schroederia ancora* G. M. Smith.
Smith (1950), p. 239, fig. 152D-G.

32. *Schroederia setigera* (Schroeder) Lemmermann.
Smith (1950), p. 239, fig. 152A-C; Prescott (1951), p. 256, pl. 57, fig. 4; Thompson (1959), p. 134, fig. 6.113.

33. *Selenastrum* sp. 1.
Fritsch (1935), p. 164, fig. 46A; Skuja (1948), p. 141, pl. 16, fig. 13; Smith (1950), p. 266, fig. 184; Prescott (1951), p. 256, pl. 46, fig. 10, pl. 57, fig. 9-11; Thompson (1959), p. 138, fig. 6.158.

34. *Sphaerocystis schroeteri* Chodat.
Fritsch (1935), p. 127, fig. 33A, B; Smith (1950), p. 116, fig. 55; Prescott (1951), p. 83, pl. 3, fig. 6,7; Thompson (1959), p. 130, fig. 6.82; Palmer (1962), pl. 5.

35. *Spirogyra crassa* Kuetzing.
Prescott (1951), p. 312, pl. 72, fig. 7, 8.

36. *Spondylosium* cf. *pulchrum* Archer.
Thompson (1959), p. 142, fig. 6.224.

37. *Staurastrum paradoxum* Meyen.
Smith (1950), p. 328, fig. 239C; Skuja (1956), p. 223, pl. 37, fig. 15, pl. 38, fig. 1-8; Palmer (1962), pl. 1.

38. *Tetraedron caudatum* (Corda) Hansgirg.
Fritsch (1935), p. 152, fig. 40H; Smith (1950), p. 269, fig. 188B; Prescott (1951), p. 263, pl. 59, fig. 17, 20-22; Skuja (1956), p. 177, pl. 28, fig. 17-19.

39. *Tetraedron hastatum* (Rabenhorst) Hansgirg.
Smith (1950), p. 269, fig. 188A; Prescott (1951), p. 265, pl. 59, fig. 26,27.

40. *Tetraedron minimum* (A. Braun) Hansgirg.
Fritsch (1935), p. 152, fig. 4B-G; Skuja (1948), p. 133, p. 15, fig. 19; Prescott (1951), p. 267, pl. 60, fig. 12-15; Skuja (1956), p. 175, pl. 26, fig. 18,19.

41. *Tetraedron muticum* (A. Braun) Hangirg.
Prescott (1951), p. 267, pl. 60, fig. 16-18; Silva and Papenfuss (1953), p. 17, fig. 27; Palmer (1962), pl. 3.

42. *Tetraedron regulare* Kuetzing.
Skuja (1948), p. 134, pl. 15, fig. 20 (doubtful - probably *T. trigonum*); Prescott (1951), p. 269, pl. 60, fig. 24-26; pl. 61, fig. 1-10; Skuja (1956), p. 177, pl. 28, fig. 17, 18; Thompson (1959), p. 136, fig. 6.153.

43. *Tetraedron trigonum* (Naegeli) Hansgirg.
Skuja (1948), p. 134, pl. 15, fig. 21; Smith (1950), p. 269, fig. 188c; Prescott (1951), p. 270, pl. 61, fig. 11, 12, 14-16; Skuja (1956, p. 176, pl. 28, fig. 12-16.

44. *Treubaria crassispina* G. M. Smith.
Smith (1950), p. 258, fig. 171E-G; Thompson (1959), p. 136, fig. 6.154.

45. *Treubaria triappendiculata* Bernard.
Smith (1950), p. 258, fig. 171A-D; Skuja (1956), p. 177, pl. 28, fig. 22,23.

46. *Trochiscia obtusa* (Reinsch) Hansgirg (Questionable).
Smith (1950), p. 255, fig. 166.

47. Unidentified "Coccomyxaceae".

EUGLENOPHYCEAE

48. *Euglena*, sp. 1.
Fritsch (1936), p. 726, fig. 239A-D,G,H, fig. 240A-I, K-O; Skuja (1948), p. 183, pl. 21, fig. 2-19, pl. 22, pl. 23, fig. 1-16; Jahn and Jahn (1949),

p. 64, fig. 72-78; Smith (1950), p. 353, fig. 255; Skuja (1956), p. 228, pl. 40, fig. 1-18, pl. 41, fig. 1-16; Thompson (1959), p. 123, fig. 6.2, 6.3, 6.4; Calaway and Lackey (1962), p. 57, fig. 50-61; Palmer (1962), pl. 3,5; Kudo (1966), p. 351, fig. 121.

BACILLARIOPHYCEAE

49. Amphora ovalis Kuetzing.
Van Heurck (1896), p. 125, fig. 24c, p. 127, pl. 1, fig. 16-21; Fritsch (1935), p. 571, fig. 188A,A',A"; Smith (1950), p. 501, fig. 414; Cleve-Euler III (1953b), p. 90, fig. 667; Patrick (1959), p. 186, fig. 7.46; Patrick and Freese (1961), p. 255, 256, pl. 3, fig. 17; FWPCA (1966), p. 61, fig. 89.

50. Asterionella formosa Hassal.
Van Heurck (1896), p. 320, fig. 77, pl. 11, fig. 439-441 (Not the marine species, A. bleakelyi W. Smith, called a variety of A. formosa); Hustedt (1931-59), p. 251, fig. 729, 730; Smith (1950), p. 481, fig. 388; Cleve-Euler II (1953a), p. 76, fig. 401; Patrick (1959), p. 178, fig. 7.11; FWPCA (1966), p. 37, fig. 41.
Syn: A. gracillima (Hantzsch) Heiberg. in Hustedt (1931-59), p. 252, fig. 731; Fritsch (1935), p. 600, fig. 200D (Under A. gracillima Heiberg); Skuja (1948), p. 324, pl. 36, fig. 2-5; Cleve-Euler II (1953a), p. 76, fig. 401B; FWPCA (1966), p. 37, fig. 42.

51. Cyclotella meneghiniana Kuetzing.
Van Heurck (1896), p. 447, pl. 22, fig. 656; Hustedt (1927-30), p. 341, fig. 174; Smith (1950), p. 463, fig. 371; Cleve-Euler I (1951), p. 48, fig. 63, pl. 4, fig. a,b; FWPCA (1966), p. 26, fig. 19; Kobayasi (1968), p. 96, pl. 1, fig. 8, 9.

52. Cymatopleura solea (Brébisson) W. Smith.
Van Heurck (1896), p. 366, fig. 119, pl. 12, fig. 482b; Cleve-Euler V (1952), p. 95, fig. 1519; Patrick (1959), p. 181, fig. 7.25; FWPCA (1966), p. 86, fig. 136.

53. Cymbella cf. tumida (Brébisson) Van Heurck.
Van Heurck (1896), p. 148, pl. 1, fig. 42; Cleve-Euler IV (1955), p. 166, fig. 1255; FWPCA (1966), p. 59, fig. 85.

54. Cymbella turgida (Gregory) Cleve.
Cleve-Euler IV (1955), p. 123, fig. 1176; Cholnoky (1957a), p. 48, pl. 2, fig. 52; Cholnoky (1957b), p. 60, fig. 31-37; Cholnoky (1960), pl. 3, fig. 107-111; Patrick and Freese (1961), p. 267, pl. 4, fig. 5; FWPCA (1966), p. 59, fig. 86.

55. Cymbella sp. 1.
Van Heurck (1896), p. 140, fig. 26, pl. 1, fig. 22-43, pl. 25, fig. 695-699; Fritsch (1935), p. 568, fig. 187D; Smith (1950), p. 500, fig. 413; Cleve-Euler IV (1955), p. 122, fig. 1176-1260; Patrick (1959), p. 186, fig. 7.47; Patrick and Freese (1961), p. 258, pl. 4, fig. 1-7; FWPCA (1966), p. 57, fig. 80-87.

56. Diatoma vulgare Bory.
Van Heurck (1896), p. 348, fig. 102, pl. 11, fig. 465, 466; Hustedt (1931-59) p. 96, fig. 628; Smith (1950), p. 477, fig. 384C; Cleve-Euler II (1953a), p. 21, fig. 329; Patrick (1959), p. 176, fig. 7.4; FWPCA (1966), p. 35, fig. 39; Patrick and Reimer (1966), p. 110, pl. 2, fig. 10-14.

57. Epithemia turgida (Ehrenberg) Kuetzing.
Van Heurck (1896), p. 294, fig. 66, pl. 9, fig. 346-349; Cleve-Euler V (1952), p. 39, fig. 1410; Patrick (1959), p. 182, fig. 7.29; FWPCA (1966), p. 83, fig. 132.

58. Fragilaria cf. capucina Desmazieres.
Van Heurck (1896), p. 325, pl. 11, fig. 446-449; Hustedt (1931-59), p. 144, fig. 659; Cleve-Euler II (1953a), p. 45, fig. 357; Patrick (1959), p. 177, fig. 7.8; FWPCA (1966), p. 39, fig. 46; Patrick and Reimer (1966), p. 118, pl. 3, fig. 5, 6.

59. Fragilaria construens (Ehrenberg) Grunow.
Van Heurck (1896), p. 325, pl. 11, fig. 450-452; Hustedt (1931-59), p. 156, fig. 670; Cleve-Euler II (1953a), p. 33, fig. 346; FWPCA (1966), p. 40, fig. 47; Patrick and Reimer (1966), p. 125, pl. 4, fig. 4-9.

60. Fragilaria crotonensis (A. M. Edwards) Kitton.
Van Heurck (1896), p. 324, pl. 11; fig. 444, 445; Hustedt (1931-59), p. 143, fig. 658; Fritsch (1935), p. 606, fig. 203D; Smith (1950), p. 479, fig. 386; Cleve-Euler II (1953a), p. 40; FWPCA (1966), p. 40, fig. 48; Patrick and Reimer (1966), p. 121, pl. 3, fig. 11-13.

61. Gomphonema sp. 1.
Van Heurck (1896), p. 268, fig. 58, pl. 7, fig. 296-318, pl. 8, fig. 314, pl. 29, fig. 810-813; Fritsch (1935), p. 568, fig. 187I, p. 571, fig. 188B, p. 594, fig. 198E,M,P, p. 600, fig. 200F, p. 610, fig. 204 O, p. 613, fig. 205A-C; Smith (1950), p. 498, fig. 411; Cleve-Euler IV (1955), p. 170, fig. 1261-1304; Patrick (1959), p. 186, fig. 7.45; Patrick and Freese (1961), p. 247, pl. 4, fig. 8-10; FWPCA (1966), p. 54, fig. 74-79.

62. Gomphonema sp. 2.
See references under Gomphonema sp. 1.

63. Melosira granulata (Ehrenberg) Ralfs.
Van Heurck (1896), p. 444, pl. 19, fig. 621 (right figures), 622; Hustedt (1927-30), p. 248, fig. 104-105; Smith (1950), p. 462, fig. 370; Cleve-Euler I (1951), p. 24, fig. 15; FWPCA (1966), p. 20, fig. 4.

64. Melosira varians Agardh.
Van Heurck (1896), p. 441, fig. 165, pl. 18, fig. 611; Hustedt (1927-30), p. 240, fig. 100; Fritsch (1935), p. 618, fig. 206F, p. 636, fig. 214A-C; Cleve-Euler I (1951), p. 29, fig. 20; FWPCA (1966), p. 21, fig. 8.

65. Melosira sp. 1.
Van Heurck (1896), p. 438, fig. 165-168, pl. 18, fig. 608-613, pl. 19, fig. 614-624; Hustedt (1927-30), p. 221, fig. 93-117 (Not fig. 94c or 118-120); Fritsch (1935), p. 580, fig. 193A, p. 600, fig. 200I,J, p. 602, fig. 201H, P. 618, fig. 206D,F,G, p. 636, fig. 214A-E; Smith (1950), p. 462, fig. 370; Cleve-Euler I (1951), p. 17, fig. 8-31; Patrick (1959), p. 187, fig. 7.51; FWPCA (1966), p. 19, fig. 1-8.

66. Navicula sp. 1.
Smith (1950), p. 488, fig. 396; Cleve-Euler V (1952), p. 7, fig. 1318, 1319, 1349-1359, 137701383; Cleve-Euler III (1953b), p. 55, fig. 707-917; Cleve-Euler IV (1955), p. 3, fig. 971-975; Patrick (1959), p. 185, fig. 7.43; Hustedt (1960--), p. 1, fig. 1180-1788; Patrick and Freese (1961), p. 189, pl. 1, fig. 20-25, pl. 2, fig. 1-19; FWPCA (1966), p. 72, fig. 109-126; Patrick and Reimer (1966), p. 439, pl. 39-52.

67. Navicula sp. 2.
See references under Navicula sp. 1.

68. Navicula sp. 3.
See references under Navicula sp. 1.

69. Nitzschia acicularis W. Smith.
Van Heurck (1896), p. 405, pl. 17, fig. 571; Cleve-Euler V (1952), p. 92, fig. 1509; FWPCA (1966), p. 90, fig. 142.

70. *Nitzschia* cf. *linearis* W. Smith.
Van Heurck (1896), p. 399, pl. 16, fig. 542, 543; Cleve-Euler V (1952), p. 80, fig. 1480; FWPCA (1966), p. 94, fig. 154.

71. *Nitzschia vermicularis* (Kuetzing) Grunow.
Van Heurck (1896), p. 395, pl. 16, fig. 529; Cleve-Euler V (1952), p. 72, fig. 1468.

72. *Nitzschia* sp. 1.
Van Heurck (1896), p. 382, fig. 124-126, pl. 15, fig. 490-519, pl. 32, fig. 874-876, pl. 33, fig. 877-879; Fritsch (1935), p. 571, fig. 188F,F',F", p. 586, fig. 195G,H; Smith (1950), p. 505, fig. 417; Cleve-Euler V (1952), p. 53, fig. 1425-1516; Patrick (1959), p. 180, fig. 7.23; Patrick and Freese (1961), p. 270, pl. 4, fig. 11-18; FWPCA (1966), p. 89, fig. 142-162.

73. *Rhoicosphenia curvata* (Kuetzing) Grunow.
Van Heurck (1896), p. 275, fig. 59, pl. 7, fig. 319; Hustedt (1931-59), p. 430, fig. 879; Smith (1950), p. 485, fig. 394; Cleve-Euler III (1953b), p. 52, fig. 601; Patrick (1959), p. 179, fig. 7.19; FWPCA (1966), p. 52, fig. 71; Patrick and Reimer (1966), p. 282, pl. 20, fig. 1-5.

74. *Stephanodiscus niagarae* Ehrenberg.
Van Heurck (1896), p. 520, fig. 273; Smith (1950), p. 463, fig. 372; Patrick (1959), p. 188, fig. 7.57; FWPCA (1966), p. 30, fig. 29.
Syn: *S. astrae* var. *niagarae* (Ehrenberg) Grunow *in* Cleve Euler I (1951), p. 53, fig. 70i-k.

75. *Surirella ovata* Kuetzing.
Cleve-Euler V (1952), p. 122, fig. 1566; Gandhi (1961), pl. 4, fig. 76, 77; FWPCA (1966), p. 88, fig. 140.

76. *Synedra arcuata* (Oestrup) A. Cleve-Euler.
Cleve-Euler II (1953a), p. 68, fig. 388B.

CHRYSOPHYCEAE

77. *Bicoeca crystallina* Skuja.
Skuja (1956), p. 306, pl. 54, fig. 1-5.

78. *Bicoeca lacustris* J. Clark.
Fritsch (1935), p. 751, fig. 245N; Huber-Pestalozzi (1941), pl. 81, fig. 350; Skuja (1948), p. 297, pl. 34, fig. 1-5 (Under *Bicocoeca lacustris* J. Clark); Lackey (1959), p. 201, fig. 8.23c.

79. *Bicoeca* cf. *multiannulata* Skuja.
Skuja (1948), p. 298, pl. 34, fig. 6-11 (Under *Bicocoeca multiannulata* Skuja); Skuja (1956), pl. 53, fig. 24a; Lackey (1959), p. 201, fig. 8.23d.
Bourrelly regards this species as a variety of *B. planktonica* Kissilew.
The specimens resembled *B. campanulata* (Lackey) Bourrelly em. Skuja in Skuja (1956), p. 304, pl. 53, fig. 33-35, *B. paropsis* Skuja in *Ibid*., p. 305, pl. 53, fig. 37-39, and *B. planktonica* Kissilew.

80. *Bicoeca* sp. 1.
Fritsch (1935), p. 751, fig. 245E,N; Huber-Pestalozzi (1941), pl. 81, fig. 349-355; Skuja (1948), p. 297, pl. 34, fig. 1-11 (Under *Bicocoeca*); Skuja (1956), p. 303, pl. 53, fig. 21-39, pl. 54, fig. 1-12; Lackey (1959), p. 201, fig. 8.23; Kudo (1966), p. 407, fig. 142a (Under *Bicocoeca*).
This genus was first described as *Bicocoeca*.
Specimens resembled *B. mitra* Fott var. *suecica* Skuja (1956), p. 303, pl. 53, fig. 27-30.

81. *Codonomonas annulata* Lackey (Questionable).
Lackey (1959), p. 200, fig. 8.19.

Bourrelly would include this species in the genus *Bicoeca* because the lorica lacks an inward-turned oral lip.

82. *Dinobryon divergens* Imhof.

Huber-Pestalozzi (1941), pl. 66, fig. 302, pl. 67, fig. 303,304; Smith (1950), p. 424, fig. 336C; Bourrelly (1954), p. 71, fig. K1; Palmer (1962), pl. 1.

Syn: *D. cylindricum* Inhof var. *divergens* Lemmermann *in* Fritsch (1935), p. 531, fig. 174D.

83. *Mallomonas* sp. 1.

Fritsch (1935), p. 516, fig. 168H-H, L-P; Huber-Pestalozzi (1941), pl. 17-32; Jahn and Jahn (1949), p. 52, fig. 46; Smith (1950), p. 413, fig. 325; Bourrelly (1957), p. 182, fig. U, p. 183, pl. 4, fig. 20-23, pl. 5, fig. 1-54, pl. 6, fig. 1-32, pl. 7, fig. 1-21; Thompson (1959), p. 154, fig. 6.331, 6.332; Calaway and Lackey (1962), p. 20, fig. 9; Palmer (1962), pl. 1; Kudo (1966), p. 308, fig. 106e.

84. *Mallomones* sp. 2.

See references under *Mallomonas* sp. 1.

Specimens closely resembled *M. bourrellyi* Teiling (Bourrelly, 1957, pl. 6, fig. 28,29) and *M. tonsurata* Teiling (Huber-Pestalozzi, 1941, pl. 25, fig. 143, pl. 26, fig. 144).

85. *Monosiga* sp. 1.

Fritsch (1935), p. 748, fig. 244I; Skuja (1948), p. 299, pl. 34, fig. 19-23; Bourrelly (1957), p. 315, fig. PP, p. 318, pl. 11, fig. 1-5; Lackey (1959), p. 204, fig. 8.29; Calaway and Lackey (1962), p. 95, fig. 105; Kudo (1966), p. 405, fig. 141d,e.

Specimens were attached to the substrate side-by-side, so this organism may actually be a *Desmarella* sp. (Huber-Pestalozzi, 1941, pl. 83, fig. 366, 367; Bourrelly, 1957, p. 319, pl. 11, fig. 6-9; Lackey, 1959, p. 210, fig. 8.42; Boucaud-Camou, 1966, p. 193, pl. 1, fig. 4; Kudo, 1966, p. 406, fig. 141f).

86. *Pseudopedinella* sp. 1.

Carter (1937), p. 34, pl. 6, fig. 23-31; Skuja (1948), p. 253, pl. 29, fig. 25-28; Bourrelly (1959), p. 267, fig. FF, p. 268, fig. B1,B2,B3,J12,pl. 7, fig. 25-28.

87. *Rhizochrysis linnetica* G. M. Smith (Questionable).

Huber-Pestalozzi (1941), pl. 73, fig. 334; Smith (1950), p. 428, fig. 341.

This might actually be another species of Rhizochrysis (Fritsch, 1935, p. 535, fig. 176D; Huber-Pestalozzi, 1941, pl. 72; Skuja, 1956, p. 292, pl. 50, fig. 33, pl. 51, fig. 1-11; Thompson, 1959, p. 158, fig. 6.353; Kudo, 1966, p. 320, fig. 113a,b), or even some other amoeboid chrycophycean genus, but all specimens resembled *R. limnetica* most closely.

88. *Salpingoeca* cf. *frequentissima* (Zacharias) Lemmermann.

Huber-Pestalozzi (1941), pl. 85, fig. 375, 376; Skuja (1956), p. 309, pl. 54, fig. 18; Bourrelly (1957), p. 324, fig. QQ10, 11.

89. *Salpingoeca* sp. 1.

Skuja (1948), p. 301, pl. 34, fig. 12-18; Skuja (1956), p. 309, pl. 54, fig. 18-21, pl. 55, fig. 2-7; Bourrelly (1957), p. 324, fig. QQ10,11, pl. 11, fig. 17; Lackey (1959), p. 207, fig. 8.35; Calaway and Lackey (1962), p. 95, fig. 106a,b; Norris (1965), p. 4, fig. 2,3,5,7,8,11; Boucaud-Camou (1966), p. 195, pl. 2, 3; Kudo (1966), p. 407, fig. 142b.

Specimens somewhat resembled *S. urceolata* Kent (Bourrelly, 1957, p. 324, pl. 11, fig. 17, Boucaud, Camou, 1966, p. 199, pl. 2, fig. 1), which Boucaud-Camou (1966) regards as synonymous with *S. cardiforma* Ellis (Norris, 1965, p. 4). Also, specimens somewhat resembled *S. infusionum* Kent (Boucaud-Camou, 1966, p. 198, pl. 2, fig. 4).

XANTHOPHYCEAE

90. *Ophiocytium capitatum* Wolle.
Huber-Pestalozzi (1941), pl. 96, fig. 411; Smith (1950), p. 396, fig. 310B; Skuja (1956), p. 335, pl. 58, fig. 17; Thompson (1959), p. 152, fig. 6.317.

DINOPHYCEAE

91. *Ceratium hirundinella* (O. F. Mueller) Schrank.
Fritsch (1935), p. 666, fig. 220G-I, L, O, p. 698, fig. 231A, F-I, p. 702, fig. 233F,P; Jahn and Jahn (1949), p. 60, fig. 65A; Huber-Pestalozzi (1950), p. 260, pl. 58, p. 254, fig. 275, p. 255, fig. 276, p. 257, fig. 276A, p. 259, fig. 276B, p. 263, fig. 277, pl. 59; Smith (1950), p. 522, fig. 429, p. 531, fig. 439; Thompson (1959), p. 162, fig. 6.391; Palmer (1962), pl. 1; Kudo (1966), p. 388, fig. 96, 135e.

92. *Peridinium* sp. 1.
Fritsch (1935), p. 666, fig. 220B-D, N, p. 695, fig. 230C,F, p. 702, fig. 233B-D,G-I,J,K,O; Jahn and Jahn (1949), p. 59, fig. 64; Huber-Pestalozzi (1950), p. 180, p. 183, fig. 171, 172, p. 187, fig. 173, p. 188, fig. 174, p. 192, fig. 175, pl. 29-56; Smith (1950), p. 519, fig. 427, fig. 529, fig. 438; Thompson (1959), p. 162, fig. 6.387-6.389; Palmer (1962), pl. 1; Kudo (1966), p. 387, p. 135c,d, p. 388.

CRYPTOPHYCEAE

93. *Cryptomonas* cf. *ovata* Ehrenberg.
Fritsch (1935), p. 654, fig. 216B,E,O,Q (Under *C. ovata* Stein); Jahn and Jahn (1949), p. 56, fig. 5b; Huber-Pestalozzi (1950), p. 46, pl. 4, fig. 24; Kudo (1966), p. 326, fig. 114a.

94. *Cryptomonas* cf. *obovoidea* Pascher.
Huber-Pestalozzi (1950), p. 50, pl. 5, fig. 25.

95. *Cryptomonas* sp. 1.
Fritsch (1935), p. 654, fig. 216A-E,O.Q; Skuja (1948), p. 351, pl. 37, fig. 27-42, pl. 38, fig. 1-16; Jahn and Jahn (1949), p. 56, fig. 56; Huber-Pestalozzi (1950), p. 38, pl. 4, fig. 24, pl. 5-8; Smith (1950), p. 633, fig. 554; Skuja (1956), p. 344, pl. 58, fig. 43,44, pl. 60, fig. 1-24; Thompson (1959), p. 166, fig. 6.413; Kudo (1966), p. 326, fig. 114a.
Possibly a species of *Rhodomonas*.

CYANOPHYCEAE

96. *Anabaena circinalis* (Harvey) Rabenhorst.
Smith (1950), p. 582, fig. 498A (Under *A. circinalis* (Kuetzing) Rabenhorst); Prescott (1951), p. 514, pl. 116, fig. 1,2,5,6 (Under *A. circinalis* Rabenhorst); Drouet (1959), p. 103.

97. *Aphanizomenon holsaticum* Richter.
Drouet (1959), p. 102, fig. 5.18.
Syn: *A. flos-aquae* (L.) Ralfs.
in Skuja (1948), p. 60; Smith (1950), p. 585, fig. 503; Prescott (1951), p. 528, pl. 122, fig. 6-8, Skuja (1956), p. 71, pl. 7, fig. 3; Palmer (1962), pl. 1.

98. Coelosphaerium cf. naeglianum Unger.
Smith (1950), p. 563, fig. 470B; Prescott (1951), p. 470, pl. 106, fig. 4.
Syn: Gomphosphaeria naegliana (Unger)
Syn: G. wichurae (Unger)
in Drouet (1959), p. 98, fig. 5.6.

99. Gomphosphaeria lacustris Chodat
Prescott (1951), p. 473, pl. 106, fig. 7,8; Drouet (1959), p. 98; Palmer (1962), pl. 1.

100. Microcystis cf. aeruginosa (Kuetzing) em. W.L., Teiling.
Prescott (1951), p. 456, pl. 102, fig. 1-4.
Syn: Anacystis cyanea (Kuetzing) Drouet and Daily.
in Drouet (1959), p. 97, fig. 5.3; Palmer (1962), p. 9.
Syn: Polycystis aeruginosa Kuetzing.
in Smith (1950), p. 556, fig. 457A.

101. Microcystis sp. 1.
Prescott (1951), p. 455, pl. 102, fig. 1-5.
Syn: Polycystis.
in Smith (1950), p. 556, fig. 457.
Syn: Anacystis.
in Drouet (1959), p. 97, fig. 5.3; Palmer (1962), p. 9, pl. 1-3.

102. Oscillatoria sp. 1.
Skuja (1948), p. 46, pl. 4, fig. 1-10; Smith (1950), p. 575, fig. 487; Prescott (1951), p. 481, pl. 108, fig. 15-20, 24, pl. 109, 110; Skuja (1956), p. 54, pl. 5, fig. 21-36, pl. 6, fig. 1-26; Drouet (1959), p. 112, fig. 5.41; Palmer (1962), pl. 2,3, p. 39, fig. 30-32.

CILIATEA

103. Codonella cratera (Leidy).
Noland (1959), p. 285, fig. 10.22g; Kudo (1966), p. 981, fig. 355m.

104. Strombidium sulcatum Claparède and Lackmann.
Hamburger and Buddenbrock (1911), p. 77, fig. 91; Wailes (1943), p. 11, fig. 26.

105. Strombidium sp. 1.
Hamburger and Buddenbrock (1911), p. 76; Wailes (1943), p. 11, fig. 26-31; Noland (1959), p. 285, fig. 10.22a; Kudo (1966), p. 979, fig. 355d.

106. Tintinnopsis cf. cylindrata Kofoid and Campbell.
Noland (1959), p. 285, fig. 10.22f; Kudo (1966), p. 98, fig. 355k.

107. Vorticella sp. 1.
Wailes (1943), p. 30, fig. 86-91; Jahn and Jahn (1949), p. 218, fig. 358; Noland (1959), p. 293, fig. 10.31b; Kudo (1966), p. 1016, fig. 368.

108. Unidentified Colepidae.
Jahn and Jahn (1949), p. 181, fig. 286; Noland (1959), p. 270, fig. 10.5b; Kudo (1966), p. 837, fig. 304a-g.

Since Noland (1959) states that, of the family Colepidae, only the genus Coleps is found in fresh water, these specimens were almost certainly Coleps spp.

109. Unidentified Oligotrichs or Tintinnids.
Jahn and Jahn (1949), p. 211, fig. 343, p. 215, fig. 351, 352; Kudo (1966), p. 979, 981, fig. 355.

SARCODINA

110. Elaeorharis cf. oculea Archer (Questionable).

Deflandre (1959), p. 261, fig. 9.119.
Syn: E. cincta Greef.
in Kudo (1966), p. 609, fig. 218e (identical figure!).

MISCELLANEOUS

111. Unidentified Colonial Alga.

Spherical multicellular colonies resembling Botryoccoccus braunii to some extent.

TAXONOMIC REFERENCES

Boucaud-Camou, Eve. 1966. Les choanoflagellés des Cotes de la Manche: I. Systématique. Bull. Soc. Linneenne de Normandie, 7: 191-209.

Bourrelly, Pierre. 1957. Recherches sur les chrysophycées, morphologie, phylogénie, systématique. Revue Algologique, Mémoire Hor-Serie, 1: 1-409.

Calaway, Wilson T. and James B. Lackey. 1962. Waste treatment protozoa. Flagellata. Florida Engineering and Industrial Experiment Station. Florida Engineering Series No. 3: 140 pp.

Carter, Nellie. 1937. New and interesting algae from brackish water. Arch. Protistenk., 90: 1-68 + 8 pl.

Cholnoky, B. J. 1957a. Neue und seltene Diatomeen aus Afrika III. Diatomeen aus dem Tugela - Flussystem, hauptsaechlich aus den Drakensbergen in Natal. Oesterreichischen Botanischen Zeitschrift, 104: 25-99.

Cholnoky, B. J. 1957b. Beitraege zur kenntnis der Suedafrikanischen Diatomeenflora. Portugaliae Acta Biologica (B), 6: 53-93.

Cholnoky, B. J. 1960. Beitraege zur Kenntnis der Diatomeenflora von Natal. Nova Hedwigia, 2: 1-128 + pl. 1-9.

Cleve-Euler, Astrid. 1951-1955. Die Diatomeen von Schweden und Finnland.
K. Svenska Vetensk.-Akad. Handl., Ser. 4. I. 2(1):163 pp. 1951.
V. 3(3):153 pp. 1952.
II. 4(1):158 pp. 1953a.
III. 4(5):255 pp. 1953b.
IV. 5(4):232 pp. 1955.

Deflandre, Georges. 1959. *Rhizopoda and Actinopoda pp. 232-264.* In *W. T.* Edmondson (ed.). Freshwater Biology. Second edition. John Wiley and Sons, Inc., New York. 1248 pp.

Drouet, Francis. 1959. Myxophyceae. pp. 95-114. In W. T. Edmondson (ed.). Freshwater Biology. Second edition. John Wiley and Sons, Inc., New York. 1248 pp.

Fritsch, F. E. 1935. The structure and reproduction of the algae. Vol. 1. Introduction, Chlorophyceae, Xanthophyceae, Chrysophyceae, Bacillariophyceae, Cryptophyceae, Dinophyceae, Chloromonodineae, Eugleneae, Colourless Flagellata. Cambridge University Press, Cambridge. 2 vols.

FWPCA. 1966. A guide to the common diatoms at water pollution surveillance system stations. U.S. Dept. of the Interior, Federal Water Pollution Control Administration, Cincinnati, Ohio.

Gandhi, H. P. 1961. The diatom flora of Bombay and Salsette Islands-II. Nova Hedwigia, 3: 469-506 + 5 pl.

Hamburger, C. and Prof. von Buddenbrock. 1911. Ciliata ohne Tintinoidea. XIII, pp. 1-152. In K. Brandt and C. Apstein (ed.), Nordisches Plankton. Zoologischer Teil, Bd. 7. Protozoa. Verlag von Lipsius und Tischer, Keil and Leipzig.

Huber-Pestalozzi, G. 1941; 1950. Das phytoplankton des Sueswassers. Systematik und Biologie. In Thienemann's Due Binnengewaesser. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

2. Teil, 1. Haelfte, Chrysophyceen, Farblose Flagellaten. Heterokonten. 365 pp. + pl. 1-107. 1941.

3. Teil. Euglenophyceen. 606 pp. + 114 pl. 1950.

Hustedt, Friedrich. 1927-1960. Die Kieselalgen. In Rabenhorst's Kryptogamen-Flora. Akademische Verlagsgesellschaft m.b.H., Leipzig. 7(1):920 pp. 1927-30.
7(2):845 pp. 1931-59.
7(3):incomplete. 1960-.

Jahn, Theodore Louis and Frances Floed Jahn. 1949. How to know the protozoa. Wm. C. Brown Co., Dubuque, Iowa. 234 pp.

Kobayasi, Hiromu. 1968. A survey of the fresh water diatoms in the vicinity of Tokyo. Japanese J. Botany, 20: 93-122.

Kudo, Richard R. 1966. Protozoology. Fifth edition. Charles C. Thomas, Springfield, Illinois. 1174 pp.

Lackey, James B. 1959. Zooflagellates. pp. 190-231. In W. T. Edmondson (ed.). Freshwater biology. Second edition. John Wiley and Sons, Inc., New York. 1248 pp.

Noland, Lowel E. 1959. Ciliophora. pp. 265-297. In W. T. Edmondson (ed.). Freshwater biology. Second edition. John Wiley and Sons, Inc., New York. 1248 pp.

Norris, Richard E. 1965. Neustonic marine craspedomonadales (choanoflagellates) from Washington and California. J. Protozool., 12: 589-602.

Palmer, C. Mervin. 1962. Algae in water supplies. An illustrated manual on the identification, significance, and control of algae in water supplies. U.S. Dept. of Health, Education, and Welfare, Public Health Service. Robert A. Taft, Sanitary Engineering Center. Publication No. 657. 88 pp.

Patrick, Ruth. 1959. Bacillariophyceae. pp. 171-189. In W. T. Edmondson (ed.). Freshwater biology. Second edition. John Wiley and Sons, Inc., New York. 1248 pp.

Patrick, Ruth and Leonard R. Freese, 1961. Diatoms (Bacillariophyceae) from Northern Alaska. Proc. Acad. Nat. Sciences of Philadelphia, 112: 129-293.

Prescott, G. W. 1951. Algae of the Western Great Lakes area exclusive of desmids and diatoms. Cranbrook Institute of Science. Bloomfield Hill, Michigan, Bull. No. 31. 946 pp.

Silva, Paul C. and George F. Papenfuss. 1953. Report on a systematic study of the algae of sewage oxidation ponds. State Water Pollution Control Board, Sacramento, California, Publication No. 7. 36 pp.

Skuja, H. 1948. Taxonomie des Phytoplanktons einiger seen in Uppland, Schweden. Symbolae Botanicae Upsalienses IX: 3. 399 pp. + 39 pl.

Skuja, H. 1956. Taxonomische und biologische Studien ueber das Phytoplankton schwedisher Binnengewaesser, Nova ActaSoc. Sci. Upsal. Ser. IV, 16: 404 pp. + 63 pl.

Smith, Gilbert M. 1950. The freshwater algae of the United States. McGraw-Hill Book Co., Inc., New York. 719 pp.

Thompson, R. H. 1959. Algae. pp. 115-170. In W. T. Edmondson (ed.). Freshwater biology. Second edition. John Wiley and Sons, Inc., New York. 1248 pp.

Van Heurck, Henri. 1896. A treatise on the diatomaceae. Translated by Wynn E. Baxter. William Wesley and Son, London. 558 + 35 pl.

Wailes, G. H. 1943. Canadian Pacific fauna 1. Protozoa - 1f. Ciliata, 1g. Suctoria. Fish. Res. Bd. Canada and Univ. Toronto Press, Toronto. 46 pp.

1 Accession Number

W70-08166

2 Subject Field & Group

05C,02H

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 Organization

6 Title

PLANKTON COMMUNITY AND HYDRAULIC CHARACTERIZATION PRELIMINARY TO LAKE FLUSHING

10 Author(s)

Eugene B. Welch
Ronald J. Buchanan
Ronald E. Nece
Richard H. Bogan

16 Project Designation

FWQA Project 16010--10/69

21 Note

Available from the Clearinghouse as PB 192 760, $3 in paper copy, 65¢ in microfiche

22 Citation Final report, October, 1969. 181p, 11 tab, 32 fig, 14 ref, 3 append

23 Descriptors (Starred First)

Eutrophication, *Plankton, Lakes, Standing crop, *Nutrients, Water quality, Water pollution effects, *Hydraulic models, Mathematical models, Water Pollution Control, Washington,

25 Identifiers (Starred First)

*Moses Lake (Washington), *Lake flushing, Flushing, Low-nutrient water,

27

The effect was evaluated of adding varying amounts of low-nutrient flushing water to one area of Moses Lake, a 6,500-acre highly eutrophic lake in eastern Washington. Cluster analysis of plankton data identified 6 sample groups and species groups. Temporal and spatial variations in community types and standing crops appear to be related to detention time, nitrate content, and available light. The effect of low-nutrient dilution water on lake plankton growth response indicated growth at 90% and 86% lake water. General agreement was obtained among 3 field techniques for determining time of travel through a section of upper Parker Horn. Dye studies, diurnal plankton sampling, and field observations indicate that southerly winds have a great effect on moving algae upstream into upper Parker Horn. Water movements in the lake could be simulated in a distorted Froude law hydraulic model. Removal of algae and nutrients by flushing procedures in Parker Horn and the lower lake would likely be more effective at night. Moses Lake behaves both biologically and hydraulically as though it were divided into several partially isolated regions. A tentative mathematical model has been set up for simulating the productivity and distribution of algae. Flushing Parker Horn with large slugs of low nutrient water may not be effective because of wind action transporting algae and their entrained nutrients back into the Horn together with nutrient regeneration from sediments. (WRSIC

of

Abstr

WR:
WRSI